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Centralised power control of wind farm with doubly fed induction generators

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Abstract

At the moment, the control ability of wind farms is a prime research concern for the grid integration of large wind farms, due to their required active role in the power system. This paper describes the on-going work of a research project, whose overall objective is to analyse and assess the possibilities for control of different wind farm concepts. The scope of this paper is the control of a wind farm made up exclusively of doubly fed induction generators. The paper addresses the design and implementation issues of such a controller and focuses on the ability of the wind farm control strategy to regulate the wind farm power production to the reference power ordered by the system operators. The presented wind farm control has a hierarchical structure with both a central control level and a local control level. The central wind farm control level controls the power production of the whole farm by sending out reference power signals to each individual wind turbine, while the local wind turbine control level ensures that the reference power signal send by the central control level is reached. The performance of the control strategy is assessed and discussed by means of simulations illustrated both at the wind farm level and at each individual wind turbine level.

Keywords: Wind farm; Doubly fed induction generators (DFIG); Variable speed wind turbine; Power system control

1. Introduction

Throughout Europe, there is an increasing trend and demand of connecting large MW capacity wind farms to the transmission power system. The electrical power system

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becomes, therefore, more vulnerable and dependent on the wind energy production. This leads to the situation that sooner or later, the large wind farms will have to behave as active controllable components [1] in the power system. This means that they will have to share some of the duties carried out today by the conventional power plants, such as regulating active and reactive power and performing frequency and voltage control on the grid.

One major research challenge, in the present and in the next years, is therefore directed towards optimised integration of large wind farms within the electrical power grid in order to be able to comply with very onerous grid connection requirements [2–4]. These regulations are determined for wind farms connected to the transmission grid, but they apply both to onshore and offshore farms. The main attention in these requirements is drawn to the fault ride through capabilities and power control of large wind farms. In the fault ride through capability requirements, the goal is to avoid significant loss of wind turbine production in the event of grid faults. The power control requirements are regarding different power system control and stability aspects:

- *power/frequency control* ability with focus on:
    - primary control, which is an automatic global adjustment of power to frequency. It has as task to balance the instantaneous production and the power consumption in the whole area.
    - secondary control, which is a regional regulation of the power to the power reference imposed by the system operator at any time. It has as task to balance production and demand within regional zones.
- *voltage control* ability with focus on voltage regulation and reactive power capability.
- *dynamic stability* with focus on the ability of wind farms to withstand some specific grid faults without being disconnected.

The traditional wind turbines/wind farms directly connected to the distribution grid do not have such high control capabilities. These wind farms produce maximum possible power in normal operation and disconnect in the case of grid faults. They work autonomously without any centralised control. They cannot regulate their production and contribute to power system stability, as conventional power plants normally do. This situation has challenged the different wind turbine manufacturers and, therefore, the wind turbine technology has been rapidly developed over the past few years. The main trend of modern wind turbines/wind farms is clearly the variable speed operation and a grid connection through a power electronic interface, especially using the doubly fed induction generation [5]. The presence of power electronics inside wind turbines/wind farms offers enlarged control capabilities [6] and thus supports the increasingly onerous grid requirements. The attention is furthermore drawn to wind farms with centralised automatic control, which intermediates a wind farm production conditioned by the system operators demands.

The first large offshore wind farm built in Denmark according to Eltra specifications is the Horns Rev wind farm. This wind farm has a 160 MW rated power capacity and it consists of 80 Vestas V80-2 MW variable-speed wind turbines with doubly fed induction generators (DFIG). It has been used for the purpose of testing and design different control techniques and demands on the wind turbines since 2002 [7]. Another example of a large wind farm is Yerga Wind Farm, located in Spain. This wind farm consists of 37 Gamesa G47-660 kW variable-speed wind turbines also with DFIG technology. Its wind farm controller is described in [8].

The development of such large wind farms and their integration into the power systems has initiated an important research activity in the development of advanced wind farm controllers. This paper describes some results of a research project, whose overall objective is to analyse and assess the possibilities for control of different wind farm concepts, such as DFIG and High Voltage Direct Current (HVDC) concepts for the power transmission for the wind farm. The process of developing models and control strategies for such wind farms has as primer aim to optimise the operation of the wind farms considering participation in the power system control.

The scope of the present research work is the design of the wind farm control with focus on power/frequency and reactive power/voltage control. Fault ride through capability is also an important issue, but the individual wind turbine controller rather than the wind farm controller is taking hand of it.

The present paper addresses the design and the implementation issues of a control strategy for a wind farm model made up exclusively of doubly fed 2 MW induction generators. The whole wind farm control model is built-up with a hierarchical modular structure: a central wind farm controller sends out reference signals to each local wind turbine controller. This modular control structure has the advantage that, if it is desired, it is easy to extend by adding new control functions either at the central or/and at the local level.

In this paper, the attention is mainly drawn to the wind farm's controller capability to regulate the wind farm's production (secondary control). In the actual wind farm controller, the active power control with balance control, delta control, ramp limitation and the reactive power control are implemented. The dynamic performance of the developed wind farm power controller is simulated in the dynamic power system simulation tool Power Factory DIgSILENT.

The paper is organised as follows. First, the wind farm configuration is briefly presented. Then, the hierarchical control levels in the wind farm are explained. The central control level with its different control modes, ordered from the system operator level, is sending out reference signals to all the local wind turbine controllers. These controllers ensure that the overall target of the wind farm controller is reached. Finally, the performance of the control strategy, when a given power demand is required from the system operator, is assessed and discussed by means of normal operation simulations of the wind farm connected to a strong grid. Simulation results are illustrated both at the wind farm level and at each individual wind turbine level.

2. Wind farm and wind turbines configuration

A wind farm configuration is implemented in the simulation tool Power Factory DIgSILENT. This tool is specially developed for simulation of electrical power systems. In the present design and testing stage of the wind farm controller, a wind farm consisting of only three wind turbines has been selected in order to minimize the simulation time

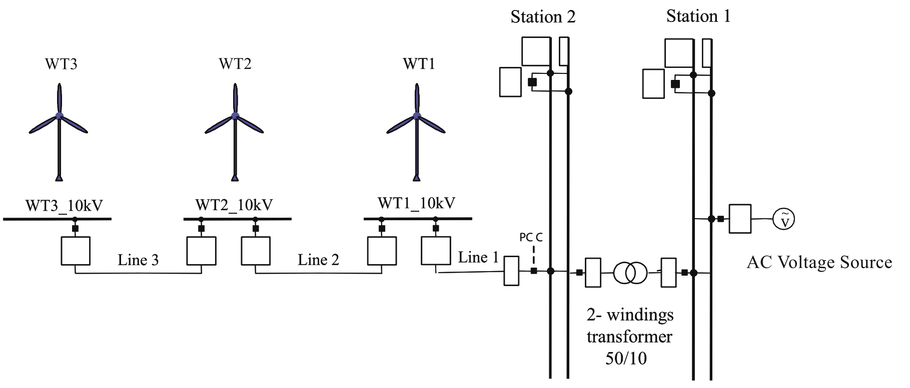

Fig. 1. Wind farm layout in DIgSILENT.

and to give a quick overview on the simulation results. However, the wind farm controller is designed to manage also large wind farms.

The wind farm consists thus of three wind turbines, each of 2 MW rated power with variable speed, variable pitch and DFIG. The wind farm is connected to a 10 kV busbar in a 50/10 kV station. A two-winding transformer is installed in the station. The network layout of the wind farm is illustrated in Fig. 1. Each of the three wind turbines WT1, WT2, WT3 are connected to its own 10 kV terminal. Both the connection of the wind farm to the station and the station itself are modelled by the actual physical components (transformers, line, busbar).

The typical DFIG configuration consists of a wound rotor induction generator (WRIG) with the stator directly connected to the grid and with the rotor interfaced through a back-to-back partial scale frequency converter, as illustrated in Fig. 2. The back-to-back converter is a bi-directional frequency converter and, therefore, it should be able to operate with power flowing in both directions. It consists of two conventional voltage source converters (rotor side converter RSC and grid side converter GSC) and a common dc-bus.

The objective of the rotor side converter (RSC) is to control independently the active power of the generator and the reactive power produced or absorbed from the grid.

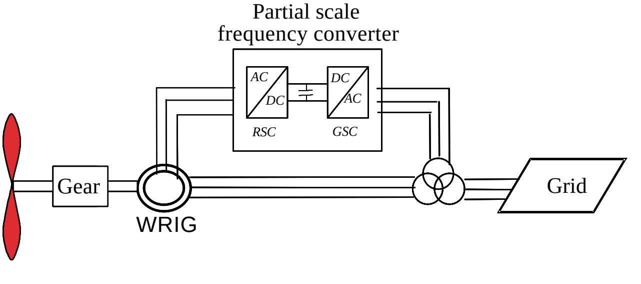

Fig. 2. Doubly fed induction generator wind turbine configuration.

The objective of the grid side converter (GRC) is to keep the dc-link voltage constant regardless of the magnitude and the direction of the rotor power and to guarantee a converter operation with unity power factor (zero reactive power). This means that the grid side converter exchanges only active power with the grid, and therefore the transmission of reactive power from DFIG to the grid is done only through the stator [9].

3. The overall control system of a wind farm with DFIG turbines

At any time and in any wind conditions, the system operator orders the production of the wind farm, namely either a maximum production or a production regulation, according to different control tasks, exactly as a conventional power plant. System operator supervises the behaviour of the wind farm through a complex control system. Depending on the actual network status, the system operator issues specific demands to the wind farm central control level, which prepares and sends further reference signals to each wind turbine local control level.

Fig. 3 sketches the overall designed control system for the wind farm with doubly fed induction generators wind turbines.

The wind farm control level behaves as a single central unit. It controls the power production of the wind farm by sending out active and reactive power references to the wind turbine control level. These power references are prepared in the wind farm control level based on several measurements in the point of common coupling (PCC) and on the available power of each individual wind turbine.

The wind turbine control level addresses the local control system of each single wind turbine and ensures that the references sent from the wind farm control level are reached. Each local wind turbine control system is also built-up with a hierarchical structure [9]. It contains a slow dynamic control level (control of speed and power) and a fast dynamic control level (electrical control of the generator currents). The slow dynamic control level provides reference signals both to the pitch system of the wind turbine and to the fast dynamic control level. This latter addresses the electrical control of the frequency converter

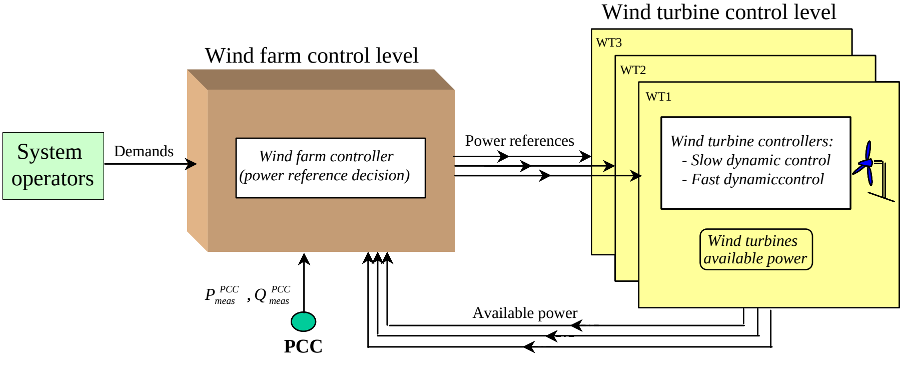

Fig. 3. Overall wind farm control.

In the following sections, the two control levels are described in more details.

4. Wind turbine control level

Fig. 4 shows the controllers of each wind turbine control level in more details. Different control strategies for variable speed wind turbines exist in the literature [9–11], where the frequency converter is used to control directly either the generator speed or the power of the wind turbine. However, independent on which control strategy is used, each individual wind turbine control level contains a slow control level (speed controller and a power controller) and a fast control level (frequency converter-rotor current controller). In the present implementation, the frequency converter controls the power of the wind turbine through two controllers in cascade. The power controller (the external controller in the cascade controllers) provides a reference rotor current to the rotor current controller (the internal controller in the cascade controllers), which further controls the generator current and thus the generator torque [12]. Beside the power controller and the rotor current controller there exists also a speed controller, which controls the generator speed to its reference value by acting on the pitch angle.

As illustrated in Fig. 4, the wind turbine control level sends information about each individual wind turbine's power capability to the wind farm controller. In the present implementation, the wind turbine's power capability is expressed in terms of instantaneous (short-term) available power. This is based on the maximum power tracking point (MTP) look-up table as function of the optimal speed.

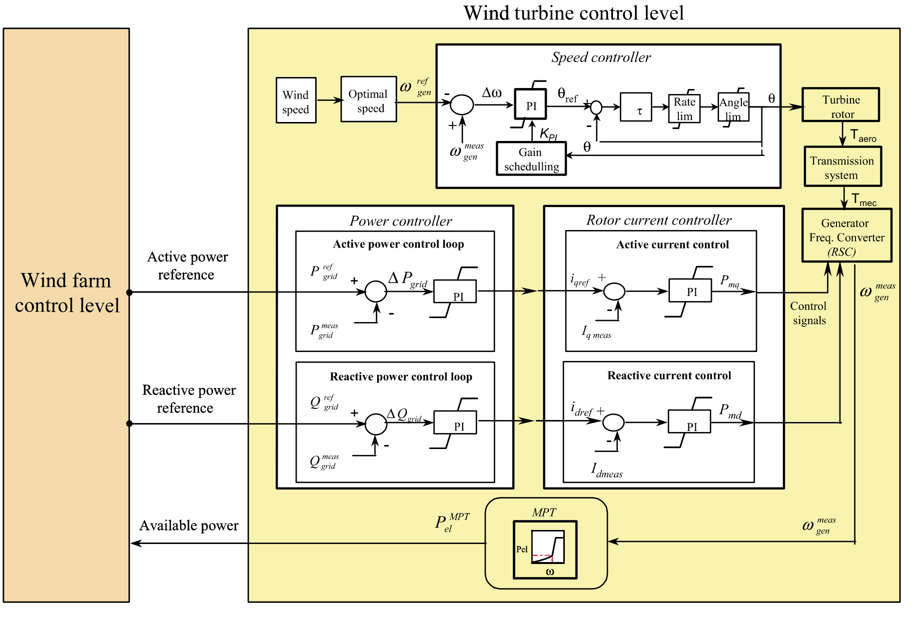

Fig. 4. Wind turbine control level.

The controller's functions are as follows:

- The power controller assures the power reference, delivered by the wind farm controller, by acting on the current reference of the rotor current controller and thus on the generator current/torque. Notice that there are two control loops: one for the active power control and the other for reactive power control. The active power control is achieved by controlling the q-axis component of the rotor current (in a stator flux dq reference frame), while the reactive power control is achieved by controlling the d-axis component of the rotor current (the magnetising current) collinear with the stator flux [9]. The rotor current controller generates rotor voltage components as control variables of the converter.
- The speed controller assures the generator speed operation by acting on the pitch angle.

Notice in Fig. 4 that the active and reactive power references for the power controller are determined centrally in the wind farm control level, based on the control strategy required for each specific wind turbine. The wind farm controller is designed in such a way that, no matter which control strategy (maximum production or power regulation) is used, it computes and sends the references to the wind turbine control level.

Remark also that the reference for the speed controller is generated in the wind turbine control level. It is known that for a traditional variable speed wind turbine, it is desired to limit the power only when the wind speeds are larger then the rated wind speed. In these cases, the speed controller keeps the generator speed limited to the rated speed. The modern wind turbines have to be able to regulate their production and this means that they have to be able to limit their power to different power value demands, imposed by system operators. This power limitation to other values than the rated power implies a generator reference different than the rated speed. In the present implementation the speed reference is adapted continuously in order to improve the wind turbine control capabilities in the case when a power downwards regulation is required. For example, if the reference speed would be kept constant to its rated value, it would mean that the turbine would try to work at rated rotational speed even at low wind speeds. The speed controller would thus become ineffective, remaining in the lower limit even longer time. Thus, if the turbine would be ordered to produce less than it is capable, the wind turbine would use the surplus power to accelerate to rated speed before the speed controller would be able to pitch to limit the speed. In the present implementation, the reference for the speed controller is generated based on an 'optimum speed' look-up table as function of the wind speed. This characteristic is truncated at rated speed, so no speed reference over rated speed is provided. In the present implementation stage, it is assumed that the wind speed is known, but in the near future it is planned to use an estimated wind speed instead. Structural load minimization issues can be further considered in the decision of the reference speed.

The control objectives of the active power control loop are based on the following control strategies:

- *Power optimization strategy* (below rated wind speed)—where the energy capture is maximised by tracking the maximum power coefficient.

   - The power reference is the wind turbine available power. The turbine has to produce the optimum power corresponding to the maximum tracking power point look-up table.
   - The speed reference is the optimal speed. The speed controller keeps the pitch angle constant to its optimal value, while the tip speed ratio is driven to its optimal value by varying the rotational speed. The difference between the generator speed and its reference value is negative and, therefore, the controller's output θ_{ref} decreases until the controller reaches its lower limit(optimal pitch).
- *Power limitation strategy* to the rated power value (above rated wind speed)—where the power is limited to the rated power of the turbine.
   - The power reference is the rated power.
   - The speed reference is the rated speed. Speed controller keeps the generator speed limited to its rated value by acting the pitch angle. The difference between the generator speed and its rated value is now positive and, therefore, the pitch angle is driven to positive values until the rated generator speed is reached.

Notice that in this control strategy, the controllers limit to the rated values of the wind turbine, i.e. the power controller assures the rated power while the speed controller assures the rated speed.

- *Power limitation strategy to a specific imposed power value* (below or above rated wind speed)—where the wind turbine is required to regulate its power and thus to produce a certain amount of power. The controllers functions in this case are as follows:
   - The power reference for each wind turbine is elaborated by the dispatch function (refer to details the next section).
   - The speed reference is determined based on the 'optimum speed' look-up table for the actual wind speed.

In this control strategy, the wind turbines have to produce less than they are capable of at a given wind speed. This action implies both a larger dynamical pitch activity and a larger steady-state pitch angle of the wind turbines. As example, Fig. 5 illustrates the steady state power-pitch curves at high wind speeds for a 2 MW wind turbine. A reduction of the power production, for example from 2 to 1 MW when the wind speed is 14 m/s, implies an increasing of the pitch angle from 8.5 to 12.5°.

5. Wind farm control level

The goal of the wind farm controller is to control centrally the active and reactive power injected by the whole wind farm into the grid. This provides the possibility to participate actively in the control tasks on the grid for the wind farms in the same way as the conventional power plants do. An overall diagram of this supervisory control level is illustrated in Fig. 6. The wind farm control level behaves as a single centralized unit, which has as inputs the system operator orders, measurements from the power common

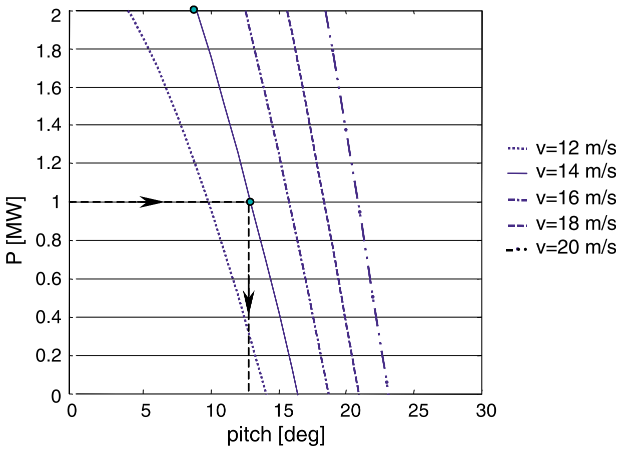

Fig. 5. Variation of power with the pitch angle for different wind speeds above rated wind speed.

coupling (PCC) and available powers from the wind turbines and as outputs the elaborated reference signals for each individual wind turbine control.

Notice that the wind farm control level receives orders on the desired type of control from the system operators. The wind farm control system contains typically a control functions block, the wind farm controller itself and a dispatch function block—see Fig. 6. At the present stage, the signal communication between the wind farm control level and the wind turbines is neglected.

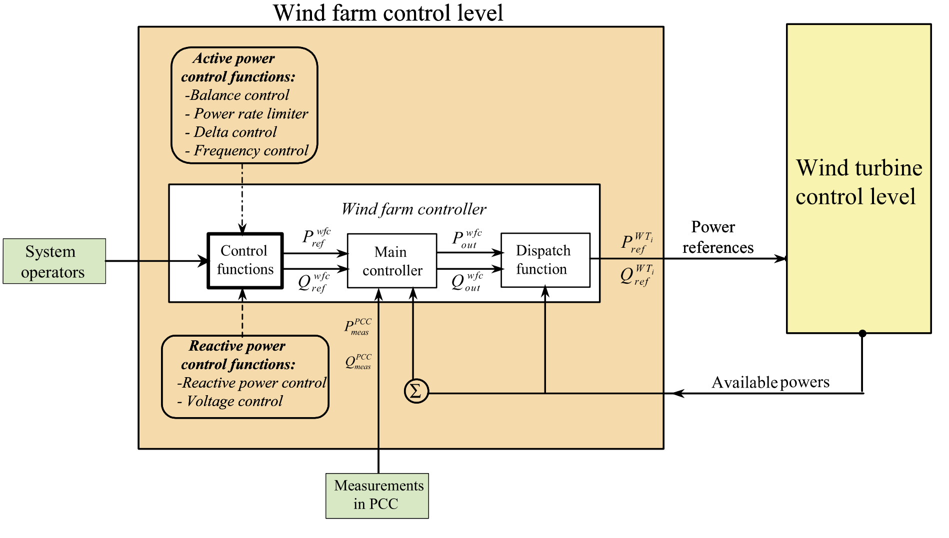

Fig. 6. Wind farm control level.

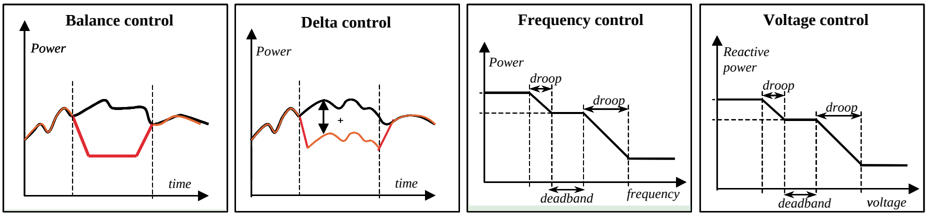

Fig. 7. Wind farm control functions.

Wind farms with variable speed doubly fed induction generators wind turbines must be able to provide advanced grid support, such as several control functions for both active power control and reactive power control [3,7], as illustrated in Fig. 7.

The active power control functions required by the system operators are as follows:

- Balance control—whereby the wind farm production can be adjusted downwards or upwards, in steps at constant levels.
- Delta control—whereby the wind farm is ordered to operate with a certain constant reserve capacity in relation to its momentary possible power production capacity. The advantage of such control is that the reserve power is available and it can be used in a frequency control action.
- Power gradient limiter—which sets how fast the wind farm power production, can be adjusted upwards and downwards. Such a limiter helps to keep the production balance between wind farms and the conventional power plants.
- Automatic frequency control—the frequency measured in the wind farm point of common coupling (PCC) is controlled. The wind farm must thus be able to produce more or less active power in order to compensate for a deviant behaviour in the frequency.

The reactive power control functions required by the system operators are:

- Reactive power control—the wind farm is required to produce or absorb a constant specific amount of reactive power.
- Automatic voltage control—the voltage in the wind farm point of common coupling (PCC) is controlled. This implies that the wind farm can be ordered to produce or absorb an amount of reactive power to the grid in order to compensate for the deviations in the voltage on the grid.

Notice that for the wind farm controller presented in this paper, it is chosen to implement both the automatic frequency control and voltage control functions in the wind farm control level. The reason for placing automatic frequency control in the wind farm control level is to avoid that the wind farm controller can counteract the frequency control implemented in the individual wind turbine [13]. The automatic voltage control is placed in the wind farm control level in order to avoid a risk of instability and a high flow of reactive power between the wind turbines. The implementation of both frequency and voltage control is going to be done as a combined droop and deadband control, as illustrated in Fig. 7.

This paper is focused on the wind farm's capability to regulate the wind farm's active and reactive power production, i.e. secondary control capability. In the present wind farm controller, the balance control and the delta control together with a power gradient limiter, as active power control functions, and the reactive power control function are thus implemented. All these control functions are implemented in such a way that they can be active at the same time. An extension of the actual wind farm controller with frequency and voltage control is in the implementation process and it will be described in details in a future paper.

In Fig. 6, notice that in the wind farm control level there are two separated control loops: one for the active power control and the other for the reactive power control. The active control loop is based on a wind farm active power controller (WFAPC) and a subordinated frequency control loop, while the reactive control loop is based on a wind farm reactive power controller (WFRPC) and a subordinated voltage control—see Fig. 8.

The principle of the active and reactive power control loops is as follows. First an active and reactive power reference signal ($P_{\mathrm{ref}}^{\mathrm{wfc}}$ and $Q_{\mathrm{ref}}^{\mathrm{wfc}}$), respectively, are elaborated in the control functions block, based on one or several control functions required by the system operator. These reference signals can be, if necessary, adjusted further with some corrections ΔP_{freq} and ΔQ_{volt} from the subordinated control loops (frequency and voltage) respectively, in order to assure that the frequency and voltage limits in PCC, are not violated. However, the possible frequency control in the PCC is limited by the limited active power reserve, while the voltage control in PCC is limited by the limited reactive power available in the wind turbines.

As in the present paper the attention is drawn to the wind farm's capability to regulate the wind farm's active and reactive power production, the frequency and voltage subordinated control loops are neglected, their corrections being assumed zero. The placement of these subordinated control loops is, therefore, pointed out in Fig. 8 by dashed lines, to be considered in a further extension of the wind farm controller.

Each loop consists of a PI controller with antiwind-up that has to ensure a correct power production from the farm. The controller computes a power error and sets up the power reference ($P_{\mathrm{out}}^{\mathrm{wfc}}$, $Q_{\mathrm{out}}^{\mathrm{wfc}}$, respectively) for the whole wind farm. These power references are further used by a dispatch function block—see Fig. 6. In this block, they are converted into power reference signals for each individual wind turbines of the wind farm. There are different ways to design the dispatch function but the one presented in this paper simply distributes the power references to the wind turbines $P_{\mathrm{ref}}^{\mathrm{WT}_i}$, $Q_{\mathrm{ref}}^{\mathrm{WT}_i}$ ($i=1{:}n$) based on a proportional distribution of the available active and reactive power, respectively

$$P_{\mathrm{ref}}^{\mathrm{WT}_i} = \frac{P_{\mathrm{av}}^{\mathrm{WT}_i}}{P_{\mathrm{av}}^{\mathrm{WF}}} P_{\mathrm{out}}^{\mathrm{WFC}}, \qquad Q_{\mathrm{ref}}^{\mathrm{WT}_i} = \frac{Q_{\mathrm{av}}^{\mathrm{WT}_i}}{Q_{\mathrm{av}}^{\mathrm{WF}}} Q_{\mathrm{out}}^{\mathrm{WFC}} \tag{1}$$

where the total active and reactive power of the wind farm are expressed as follows:

$$P_{\mathrm{av}}^{\mathrm{WF}} = \sum_{i=1}^{n} P_{\mathrm{av}}^{\mathrm{WT}_i}, \qquad Q_{\mathrm{av}}^{\mathrm{WF}} = \sum_{i=1}^{n} Q_{\mathrm{av}}^{\mathrm{WT}_i} \tag{2}$$

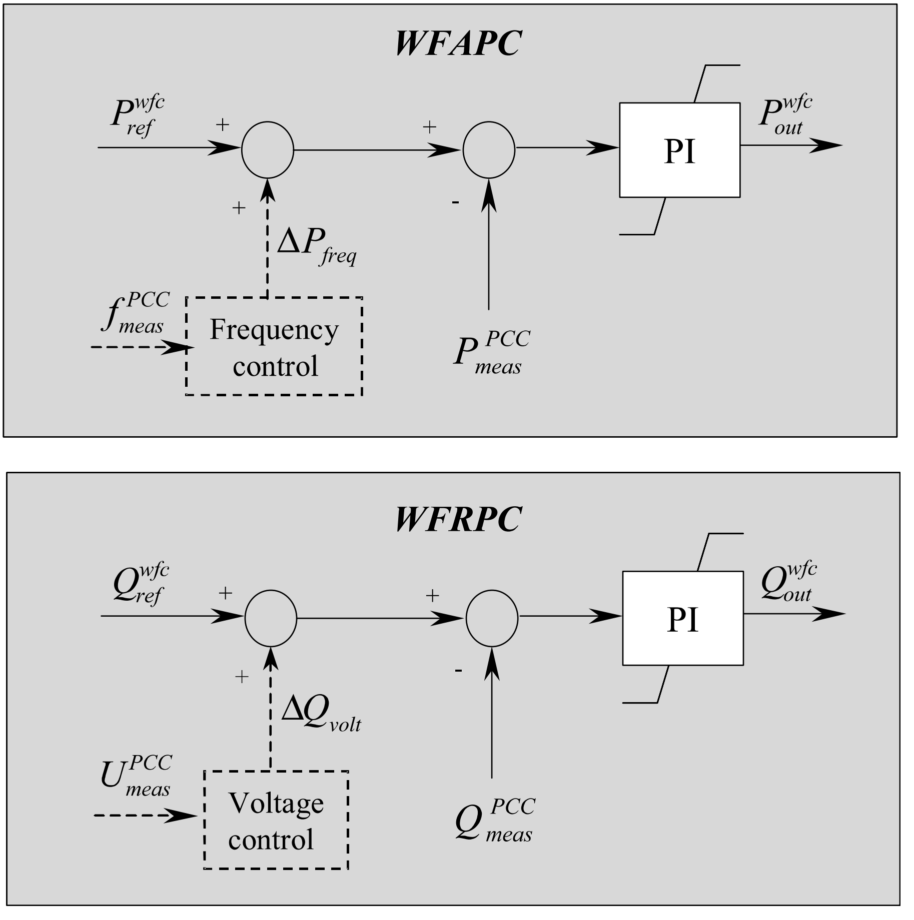

Fig. 8. Wind farm controller.

and where $P_{\mathrm{av}}^{\mathrm{WT}_i}$ is the available power for the ith wind turbine in one specific moment given by the maximum power tracking point (MTP) look-up table (see Fig. 4). $Q_{\mathrm{av}}^{\mathrm{WT}_i}$ is the available reactive power of the ith wind turbine, computed based on the generator rated apparent power for each wind turbine, as follows:

$$Q_{\mathrm{av}}^{\mathrm{WT}_i} = \sqrt{(S_{\mathrm{gen\_rate}}^{\mathrm{WT}_i})^2 - (P_{\mathrm{av}}^{\mathrm{WT}_i})^2} \tag{3}$$

6. Simulation results

Different scenarios are simulated to illustrate how the developed wind farm controller controls the wind farm power production to the reference power ordered by the system

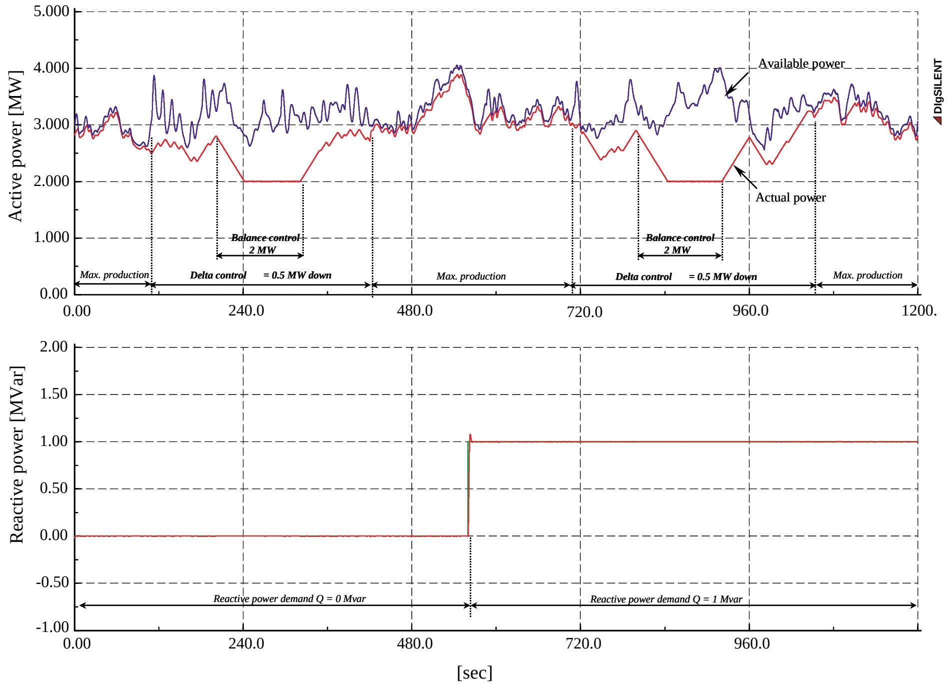

Fig. 9. Wind farm control level: maximum production, delta control, balance control, ramp limiter. At time 560 s the reactive power reference is changed from 0 to 1 MVar.

operators. The controller's performance is assessed and discussed by means of normal operation simulations of the considered 6 MW wind farm connected to a strong grid. The attention in these simulations is mainly drawn to the power system control aspects related to the secondary control capability. The simulation results are illustrated at the wind farm level and/or at the wind turbine level, depending on their information content. Two simulation cases are considered in this paper.

Fig. 9 shows the first simulation case where the balance control, the delta control, the power gradient limiter and the reactive power control are illustrated. The wind turbines in the wind farm are driven by different turbulent winds, with 9 m/s mean speed value and 10% turbulence intensity. The focus in this simulation is on the wind farm controller performance in the PCC of the wind farm. Therefore, only the simulation results at the wind farm level are presented. Fig. 9 illustrates both the available and the actual active power and the reactive power measured in the PCC of the wind farm, when the system operators require different control actions. In order to test the wind farm controller, the following active power control functions sequence is proposed:

1. The first 100 s, the wind farm has to produce maximum power. Notice that the actual power follows the available power as long as the ramp limiter permits that.

2. The time period between 100 and 420 s a delta control is imposed. The wind farm has to operate with a 0.5 MW constant reserve capacity.
3. The time period between 200 and 320 s a balance control is imposed. The wind farm is ordered to regulate downwards to 2 MW. Notice that in this period, both the delta and the balance control are active at the same time. The adjustment upwards and downwards of the wind farm production is performed with a ramp limitation about ± 1.2 MW/min.
4. The time period between 420 and 700 s maximum power production is again ordered.

The reactive power reference for the whole wind farm $Q_{\mathrm{ref}}^{\mathrm{WF}}$ is set to zero the first 560 s. A step in the wind farm reactive power demand to 1 MVar is applied at 560 s and the previous active power control functions sequence (1–4) is repeated.

Notice that the generated active power is not altered by the step in the reactive power demand, its variations being only due to the turbulent wind.

The simulation results show a good performance of the control system. The specified references both for the active and reactive power are achieved properly.

The second simulation case has as goal to illustrate the interplay between the wind turbines of the wind farm in order to achieve the demanded set points. Therefore, the simulation results are presented both at the wind farm control level and the wind turbine control level. In this simulation, the wind turbines see different turbulent wind speeds with 16 m/s mean value and turbulence intensity of 10%. The wind farm is ordered to run with a balance power of 3 MW and a reactive power demand of 0 MVar. In order to illustrate the performance of the wind farm controller, it is considered that at the time 150 s the third wind turbine is disconnected from the farm, being thus unable to contribute with both active and reactive power.

Fig. 10 illustrates both the available active power/the actual active power and the reactive power at the wind farm level, namely in the PCC of the wind farm. The disconnection of the third wind turbine is illustrated as a step to another level of the available power. Notice that the wind farm controller manages to keep the required 3 MW actual active power and 0 MVar actual reactive power, both before and after the disconnection of the third wind turbine.

Fig. 11 illustrates the simulation results at the wind turbine control level. The first 150 s, each wind turbine has to produce 1.03 MW and absorb 0.1 MVar in order to achieve 3 MW and 0 MVar in the PCC. In the moment of disconnection of the third wind turbine, its active and reactive power reference signals become zero. The dispatch function block (see Fig. 6) recomputes then the references for the remaining two wind turbines in order to maintain the 3 MW balance power and the 0 MVar reactive power in the PCC. Notice that the wind farm keeps the required 3 MW active power very smoothly (see Fig. 10), although the active power varies at the individual wind turbines (see Fig. 11). Notice that the production of the active power and the absorption of reactive power from the two remaining wind turbines increases to compensate for the disconnected wind turbine.

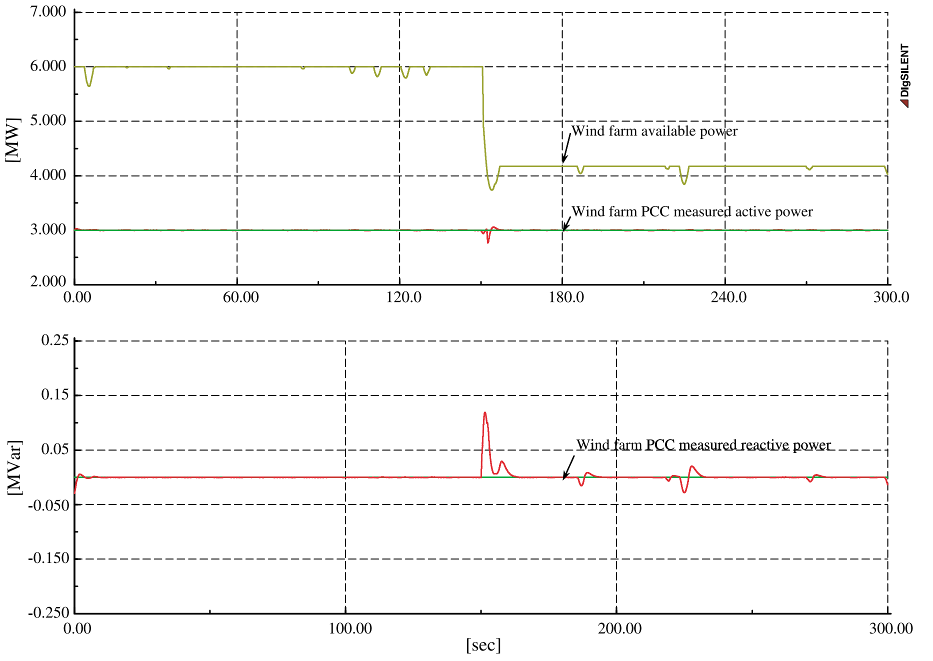

Fig. 10. Wind farm control level: the active and the reactive power of the wind farm. At the moment 150 s the third wind turbine is drops out.

7. Conclusions and future work

In this paper, the attention is mainly drawn to the capability of a wind farm controller to regulate the wind farm's production. The goal is to design a central controller, which, according to different control task imposed by the system operator, can control the active and reactive power injected by the whole wind farm into the grid.

A wind farm controller for a wind farm made up exclusively of doubly fed induction generators is designed and tested by simulations. The proposed control system is based on a complex hierarchical control architecture. A central supervisory control level decides the active and reactive power references for each wind turbine local control level, based on received production orders (maximum production or power regulation) from the system operator.

In the present simulated wind farm controller, it is implemented the balance control and the delta control together with a power gradient limiter, as active power control functions, and the reactive power control function. All these control functions are implemented in such a way that they can be active at the same time.

Simulating different control actions imposed to the wind farm controller, as for example commanded active and reactive steps, has tested the performance of the control system. The simulation results illustrate a robust power control performance.

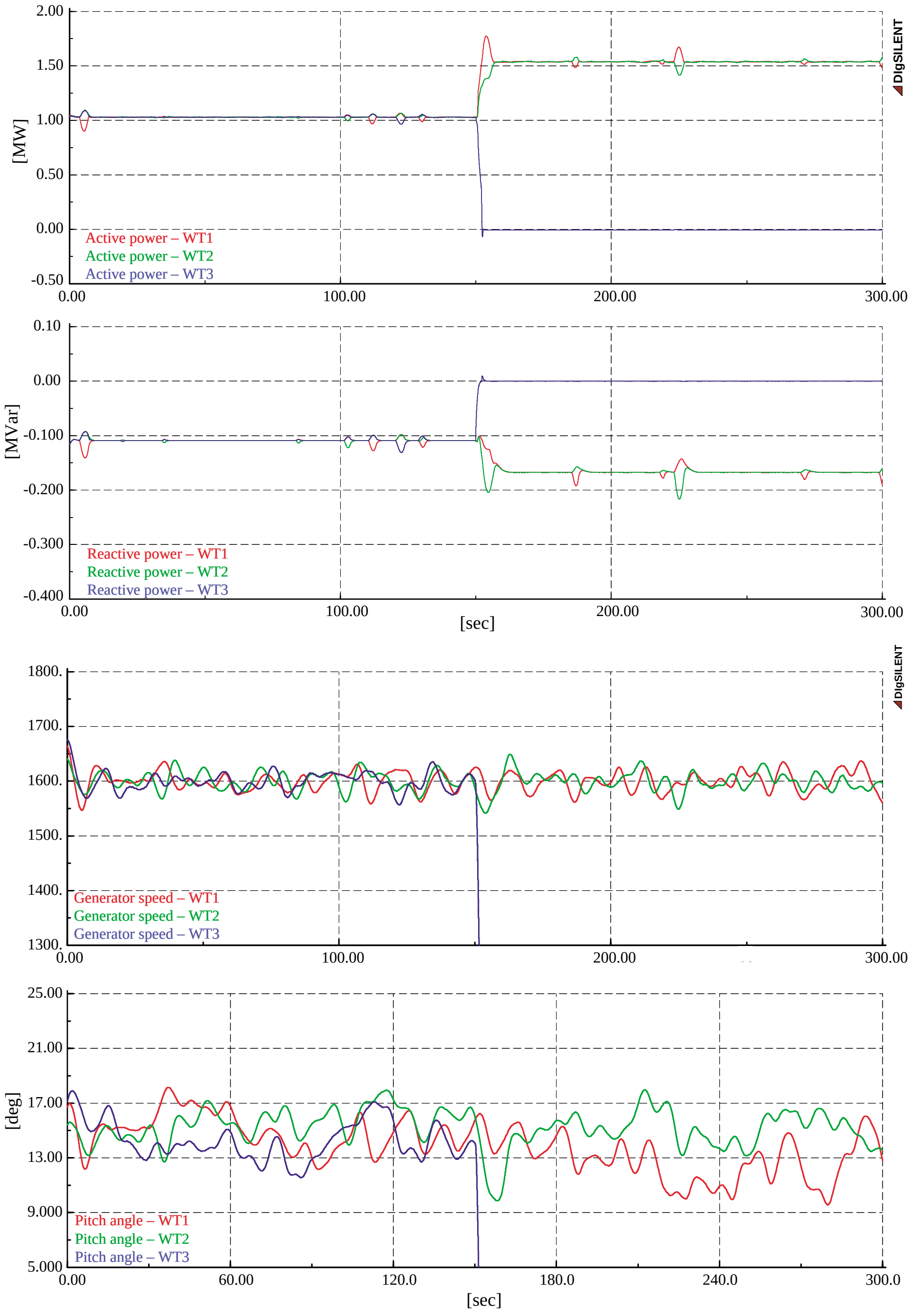

Fig. 11. Wind turbine control level: the active powers, the reactive powers, the generator speeds and the pitch angles of the wind turbines. At the moment 150 s the third wind turbine drops out.

An extension of the actual wind farm controller with frequency and voltage control is in the implementation process and it will be described in details in a future paper.

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