Centralized Control Algorithm of Active and Reactive Power Generation for Wind Farm

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Abstract-This paper has for objective the analysis and evaluation of the wind farm control possibility made up exclusively of three turbines using the doubly fed induction generator (DFIG). In purpose to control the power production according to the system operator requirements, this work addresses the implantation of the control algorithm and the capacity of the control strategy applied. The supervision algorithm has a hierarchical structure and contains two control levels. The principal control level (central) ensures the power production control of the entire wind farm; it uses the proportional distribution algorithm which allowed determining and sending the reference power signals to each individual turbine. The main advantage of this supervision algorithm, it allowed to avoid the saturation of the wind turbine production. On the other hand, the auxiliary control level (local) ensures that the reference power signal sent by the principal controller is reached. The performances of the control strategy are shown and evaluated in the simulations results obtained.

I. INTRODUCTION

Currently, the principal worry of research for a large integration of the wind farms in the electrical grid is the capacities of their control [1]. It is for the reason of their active role in the power system. The electrical system becomes, therefore, more vulnerable and depend on the wind energy production. Early or late, the situation will conduct the large wind farms to behave as active controllable components in the power system [2]. This means that they will have to share certain functions with the conventional power stations, like the regulation of the active and reactive powers, the frequency and voltage control in the grid. The principal challenge of search in the present and the future years is thus directed towards the optimization of large wind farms integration in the electrical grid in order to be able to conform to the requirements of the grid connection [3], [4]. Today, the wind farm connected directly to the grid does not have a great capacity of control. These farms produce the maximum power possible during the standard operation and are disconnected in the case of the grid faults.

They function in an autonomous way without any centralized control [5]. Thus, they cannot regulate their production and they don’t contribute to the stability of power system like the traditional power stations. This situation challenges the various manufacturers of wind turbine. The principal tendency of the modern wind farm operates at variable speed. The presence of power electronics in the farm offer a large capacity of control and supports more the requirements of the electrical grid [6].

In this paper, the centralized supervision algorithm based on the proportional distribution has been applied on the wind farm. The whole wind farm control model is built-up with a hierarchical modular structure: a central wind farm controller sends out the reference signals to each local wind turbine controller. The auxiliary control level ensures that the reference power signal sent by the principal controller is reached.

II. WIND FARM CONFIGURATION

The configuration of the wind farm considered is shown in Fig.1. It is made up exclusively of three DFIG of 1.5MW of each generator. The integral model of wind farm control has a hierarchical modular structure: The principal controller of wind farm generates the reference signals to each local controller of wind turbine.

The diagram of the wind farm is illustrated on the fig. 1. Each one of forth turbines T\textsubscript{1}, T\textsubscript{2}, T\textsubscript{3}, T\textsubscript{4} will be connected on its terminal borne of 690V. The generator consists of the doubly fed induction generator [7], where the stator is connected directly to the grid and a rotor interfaced by a multilevel converter cascade. The objective of the converter on the rotor side is the independent control of the stator active and reactive power of generator (produced or absorbed by the generator).

The objective of the converter on the grid side is to provide the uninterrupted supply for the inverter and to ensure the connection to the electrical grid with a unit power-factor (reactive power is null). This means that this converter will exchange only the active power with the network, thus the exchange of the reactive power will be effect only with the stator side [4], [5], [7].
III. WIND FARM DESCRIPTION

The system operator controls the wind farm production exactly as a conventional power station whatever the climatic conditions. A complex system of control is used by the system operator to supervise the behavior of the entire wind farm. Depending on the real state of the grid, the system operator emitted the request of active and reactive power to the principal controller of the wind farm, which prepares and sends the reference signals for each controller of the wind turbines.

The principal controller controls the power production of the wind farm, by sending the reference signals of active and reactive power to the each controller of the wind turbines. The calculation of these power references is based on:

- Various measurements on the point of common coupling (CCP);
- Available power of each wind turbine.

The controller of each wind turbine ensures that the references sends by the principal controller of the wind farm are reached. Each control system of the wind turbine contains a level of slow dynamic control (control of the powers) and a level of fast dynamic control (electric control of the generator currents).

IV. WIND TURBINE CONTROL PRINCIPLE

Fig. 2 illustrates the control principle of each wind turbine [7]. Various strategies of variable speed wind turbines control exists in the literature, where the frequency converter is used to control directly the generator speed or the power of the wind turbine.

The converter controls the wind turbine power through two controllers. The power controller provides the rotor currents references to the rotor current controller.

The wind turbine control level sends information about the available power in each wind turbine to the controller of wind farm. It will be based on the maximum power point tracking (MPPT) as function of optimal speed.

The active power control is realized by the control of the q axis component of the rotor currents with the stator flow orientation. While the reactive power control is realized by the control of the d axis component of the rotor currents (current of magnetizing) located on the same axis with the stator flow [8], [9]. The controller of the rotor currents produces the rotor voltage components as variables of the converter controller.

The objectives of the active power control are based on the following control strategies [4], [7]:

- Strategy of power optimization: where the capture of energy is maximized by applying of the maximum power algorithm.
  - The power reference is the available power of the wind turbine;
  - The speed reference is the optimal speed. The speed controller maintains the wedging angle constant to its optimal value.

- Power limitation strategy: with the nominal power value (above the mean wind speed) where the power is limited to the nominal power of the turbine.
  - The reference power is the nominal power;
  - The speed reference is the nominal speed.

- Power limitation strategy to an imposed specific value: (below or above of the mean wind speed) where the
wind turbine is required to regulate its power, thus produce a certain quantity of power.

The functions of the controllers are in this case as follow:
- The reference power for each wind turbine is elaborated by the dispatching function;
- The reference speed is determined by using a table of “optimal speeds” for the real wind speed.

In this control strategy, the wind turbines must produce less than their capability at a given wind speed. This action implies a greater dynamic activity of blade wedging of the wind turbines.

V. WIND FARM CONTROL

The wind farm controller contains a main program. It controls the active and reactive power injected to the grid by the wind farm. This can provide the possibility of taking an active part in the system services like the conventional power stations [10], [11].

The control level of the wind farm behaves like unit of centralized supervision. To elaborate the reference signals for each wind turbine, the controller of the wind farm needs like entries:
- The request of the system operator;
- The measurements of the active and reactive power from the common coupling point (CCPs);
- Available powers of the wind turbines.

Other adjustments of active and reactive powers can be required by the grid manager, like the power limitation, balancing adjustment, automatic frequency control, reactive power control, automatic voltage control [4], [12].

The references $P_f^{\text{ref}}$ and $Q_f^{\text{ref}}$, are used by the dispatching functions, where they are converted into signals of power references for each wind turbine. The dispatching function used, distributes the power references of the wind turbines $P_{i}^{\text{ref}}$, $Q_{i}^{\text{ref}}$ (i=1: n) based on the proportional distribution of the available active and reactive powers, respectively [4], [13], [14], [15]:

$$P_i^{\text{ref}} = \frac{P_i^{\text{av}}}{P_{\text{av}}} P_f^{\text{ref}}$$

$$Q_i^{\text{ref}} = \frac{Q_i^{\text{av}}}{Q_{\text{av}}} Q_f^{\text{ref}}$$

The total available active and reactive power of the wind farm is expressed as follow:

$$P_{\text{av}}^{F} = \sum_{i=1}^{n} P_i^{\text{av}}$$

$$Q_{\text{av}}^{F} = \sum_{i=1}^{n} Q_i^{\text{av}}$$

Where:

- $P_{i}^{\text{av}}$ is available active power for the $i$th wind turbine to one specific moment given by MPPT algorithm;
- $Q_{i}^{\text{av}}$ is available reactive power for the $i$th wind turbine.

The maximum reactive power absorbed or generated by a wind generator of 1.5MW is given as follow [16], [17]:

$$Q_i^{F} = \left[ \pm 1500\cos(\arcsin(P_{\text{unit}})) + 300 \right] * 10^3$$

$P_{\text{unit}}$ is linked to the aerodynamic power $P_{\text{aer}}$ by the following expression:

$$P_{\text{unit}} = \frac{1}{2} \frac{1}{800 * 10^3} \frac{P_{\text{aer}}}{2}$$

The aerodynamic power $P_{\text{aer}}$ is given by the following equation:

$$P_{\text{aer}} = \frac{\rho * S * v^3}{2}$$

Where:

- $\rho$ is the air density ($\approx 1.22$kg/m$^3$ in a standard atmosphere $25^\circ C$);
- $S$ is the surface swept by the turbine;
- $v$ is the wind speed.

VI. SIMULATION RESULTS AND DISCUSSION

The figures above illustrate the results obtained. $P_f^{\text{ref}}$ and $Q_f^{\text{ref}}$ are the references sent by the system operator. We analyze the distribution of these powers on the wind turbines which constitute the wind farm.

![Fig. 3.1. Wind profile velocities](image-url)

The wind profiles shown on figure 3.1 are supposed to differ slightly. The average speeds of the supposed are approximately 10m/s. The turbine speeds will automatically undergo the same variations as these of wind profiles, thus, the generator speeds.

Fig. 3.2 and 3.7 show the active and reactive power of the wind farm (reference, measured, and available), respectively.
The measured active and reactive powers produced (measured) by the wind farm perfectly follow the references required by the system operator. It is noticed that the total active and reactive powers generated by the wind farm do not exceed the available powers in all conditions. The maximum powers that can be produced by the wind farm are equal to the maximum powers available.

On the fig. 3.7, it is remarked that the reactive power can take different values which depend on the demand of the system operator. That means, the wind farm can operate with unit power factor (0s \leq t < 0.1s and 0.4s \leq t < 0.5s), can generate a reactive power (0.1s \leq t < 0.4s and 0.8s \leq t \leq 1s), or absorb a reactive power (0.5s \leq t < 0.8s).
contribute to satisfying the demand of the system operator in terms of active and reactive powers. Based on the same figures, the reference sent to each generator by the main controller is shown to be followed by power production that does not exceed the available power of each turbine. This point confirms the advantage of the supervision algorithm applied and its effectiveness.

The active and reactive power is produced according to the electromagnetic power available in each wind turbine. The algorithm applied take into a consideration the maximum power available. So, the power produced can never exceed the maximum.

![Fig. 3.8. Reactive powers of turbine N°01 (reference, measured and available)](image)

![Fig. 3.9. Reactive powers of turbine N°02 (reference, measured and available)](image)

![Fig. 3.10. Reactive powers of turbine N°03 (reference, measured and available)](image)

![Fig. 3.11. Reactive powers of turbine N°04 (reference, measured and available)](image)

**VII. CONCLUSION**

In this work, we have presented the centralized control algorithm which allows the distribution of the active and reactive power of the wind farm. It is based on the proportional distribution algorithm of the powers required by the system operator according to available powers of each wind turbine. The simulation results presented and evaluated above show the proportional distribution of the total powers required by the system operator and the contribution of each turbine without saturation. This advantage confirms the effectiveness of the supervision algorithm used.

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