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New management structure of active and reactive power of a large wind farm based on multilevel converter

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ABSTRACT

This paper proposes a system of supervision and operation of a new structure wherein a large wind farm is connected to an electrical grid. The farm is managed in such a manner that it can produce the power needed by the grid system. The supervision algorithm is used to distribute the active and reactive power references to the wind turbines proportionally. Based on the aerodynamic power and wind speed of each turbine, the active and reactive power references are produced individually. By using the vector field oriented control, each doubly fed induction generator is controlled through the rotor, which is connected to the two-level pulse width modulation converter. The close loop control is used to provide a constant DC voltage using a five-level neutral point clamped converter. The five-level neutral point clamped converter allows also the adaptation of the voltage level to the electrical grid with better resolution waveform. The analysis of the simulation results shows the effectiveness of the proposed system.

1. Introduction

At present, wind farms are required to conform to the requirements imposed by the system operator to increase and optimize the wind power penetration in the electrical grid [1,2]. The connection of the wind farm to the electrical grid without affecting its safety and stability is a great matter of concern. In terms of the structure of the wind farm, the use of multilevel converters for the electrical grid connection is an interesting mechanism, particularly when employed in large power production systems [3–5]. By exploiting their advantages [6,7], the connection of the renewable energy sources to the electrical grid can be improved. Previously, when only one wind turbine was considered, supervision algorithm was not required to supervise the global system. In this case only simple control was sufficient. The integration of the wind farms in the electrical grid has been increased and new standards has been introduced on the minimum power rate, voltage level and the frequency tolerance to manage the interconnection. Therefore, the wind farms are become large and constituted of many wind turbines where the active and reactive powers are required to be well supervised to satisfy the demand of the grid. Therefore, researchers orient their research towards the supervision algorithms of the wind farms and their connection to the power system. Several supervision control techniques of wind farms are currently being investigated. These include active and reactive power control [8,9], voltage control [10,11], frequency control [12] and the tolerance in relation to electrical grid faults. The strategy investigated consists of exploiting the abundance effect within the farm. To derive an adequate distribution of the active and reactive powers on the wind turbines, a better support for the electrical grid should be ensured. Several distribution algorithms of the active and reactive powers are proposed such as supervision algorithms based on PI controller [13–17], and supervision algorithms based on optimization functions [18–20]. The use of these algorithms does not distribute the active and reactive reference power proportionally and causes the saturation of some wind turbines while the others are able to provide more active or reactive power. Other supervision algorithms are based on a proportional distribution of the active and reactive powers [9,21,22]. These algorithms can ensure that all the

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wind turbines of the wind farm function sufficiently beyond their maximum capacities of production. Thus, the risk of saturation is prevented. In cases where one of the wind turbines is saturated, i.e., the wind turbine evolves with its maximum of production or consumption of the reactive power, the missing power is sourced from the other wind turbines; thus, the request is satisfied.

Furthermore, the wind farm structure can contribute in the power produced optimization by using the new technology as multilevel converters and new supervision algorithms. Also, the interconnection manner between the different wind turbines inside the wind farm can enhance the performance of the global system, thus, the cost is reduced. Lately, different studies on the wind farms have been carried out [1,8,9], but their internal configurations were never discussed.

This paper addresses the design and the implementation issues of a new management structure of a large wind farm model comprising doubly fed induction generators (1.5 MW). The new structure is proposed to optimize the configuration of the future wind farms using multilevel converters and the proportional distribution algorithm. The advantage of the proposed system is the elimination of the transformer previously used for the connection of the rotor to the grid. In addition, all turbines contribute to the produced power without saturation to satisfy the references set by the system operator. The entire 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 stators of doubly fed induction generators (DFIGs) are connected in parallel. Each rotor is connected to a two-level converter and the four DC voltages are provided by using one five-level neutral point clamped (NPC) converter, which likewise ensures the connection to the electrical grid.

2. Description of the wind farm

The wind farm considered is illustrated in Fig. 1. It consists of four wind turbines, each with the same nominal power (1.5 MW). Each wind turbine is composed of a turbine, gearbox, DFIG, and two-level converter connected to the rotor (RSC). The RSCs supply the rotor winding of each generator and control power flow by controlling the rotor currents. The quadrature component controls the active power and the direct component controls the reactive power. The four DC voltages are provided by only one grid side five-level converter (GSC), which also ensures the connection to the electrical grid. GSC controls the grid currents and regulates DC voltage. The stator winding of the generators are connected in parallel.where:

- P_{si_ref} and Q_{si_ref} (i=1,2,3,4): stator active and reactive power references of each turbine;
- $P_{Ti\_available}$ and $Q_{Ti\_available}$ (i=1,2,3,4): active and reactive power available in each turbine;
- P_{meas} and Q_{meas}: measured active and reactive power;
- P_{ref} and Q_{ref}: active and reactive power reference sent by system operator;
- :v_i (i=1,2,3,4): wind velocities;
- i_{sA-i} (i=1,2,3,4): stator currents of each generator;
- i_{ri} (i=1,2,3,4): rotor currents of each generator;
- i_{r-ABC}: currents in the grid side converter;
- V_{r-ABC}: voltages in the grid side converter;
- i_{di} and I_{reci} (i=1,2,3,4): direct and the rectifier currents;
- U_{C-meas}: measured DC-voltage.

The diagram with a full configuration of each wind turbine is shown in Fig. 2.

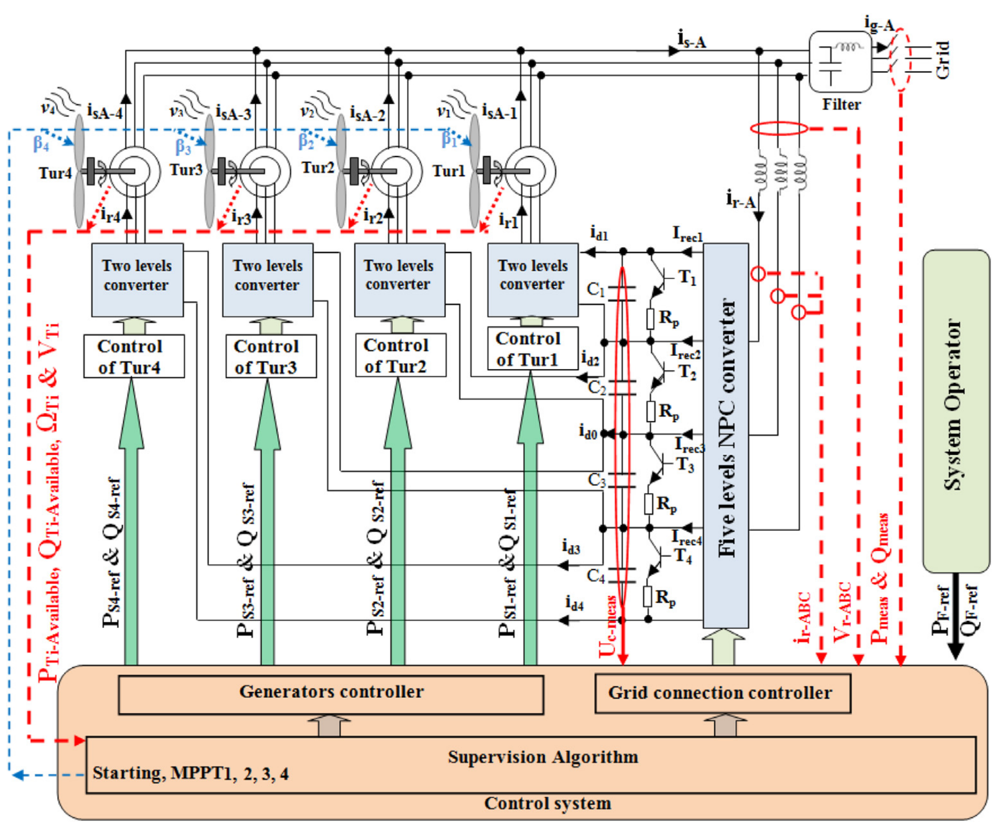

Fig. 1. Wind farm description.