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Operation and coordinated control of fixed and variable speed wind farms

J.L. Rodríguez-Amenedo[a,*], S. Arnaltes[a], M.A. Rodríguez[b]

[a]Department of Electrical Engineering, Universidad Carlos III de Madrid, Av. de la Universidad, 30, 28911 Leganés, Madrid, Spain
[b]Faculty of Engineering, University of Mondragon, Loramendi, 4. Apartado 23, 20500 Arrasate, Mondragon, Spain

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Abstract

This paper will describe the possibilities of coordinated control and management for different wind farm concepts to guarantee that operational set points of active and reactive power, specified by the Spanish transmission system operator (TSO), are reached. This coordinated control has been designed and implemented by a hierarchical and robust control structured from a central control level to each wind farm control board and finally to an individual wind turbine level. This article will demonstrate that both technologies, fixed and variable speed based wind farms can contribute to power and voltage control. In particular, this paper will deal with the use of under-load tap changing transformers in the point of common coupling of the wind farm with the grid, and the reactive power compensation by means of convectional mechanical switched capacitors enhancing the integration of the fixed speed wind farms in the power system.

Keywords: Wind farms; Power system control; Variable speed wind turbines; Fixed speed wind turbines

1. Introduction

The world market for wind power capacity is growing continuously. Wind power of 7588 MW capacity was installed during 2006 in the EU, according to the annual statistics issued by the European Wind Energy Association (EWEA), an increase of 23% compared to 2005. In the American market wind power generating capacity increased by 27% in 2006 and is expected to increase an additional 26% in 2007. Spain is the second wind energy market in the world, at present the power installed is 11,500 MW and a prospect for the year 2011 is 20,000 MW will be the installed capacity. This high wind power penetration demands that wind farms be compliant with rules and operation guidelines of international grid codes.

In the last few years, operation and control ability of wind farms has been one of the most important tasks for the Spanish transmission system operator (TSO), due to the high increment of the wind energy capacity connected to the grid and, specifically, at the high voltage transmission network. This new scenario has modified the traditional criteria for operating the Spanish power system with the same confidence levels of reliability and security that existed in the past when this high amount of variable energy did not exist in the generation mix.

It is well known that traditional fixed speed wind turbines (FSWT) directly connected to the grid do not have high control capabilities, and cannot guarantee low voltage ride-trough capability due to voltage dips. Although this scenario is changing due to the great efforts of wind turbine manufacturers and wind farm owners, the TSO is requesting a real convergence of wind energy with operation of conventional power plants.

This situation has lead to the recent publication of technical documents (grid codes) for regulating all aspects related with integration of wind farms in the power systems [1–3]. At present, in Spain, it is mandatory for all wind farms with a power capacity higher than 10 MW to be connected to a dispatching centre [4] with some specific

*Corresponding author. Tel.: +34 91 6245992; fax: +34 91 6249430.
E-mail addresses: amenedo@ing.uc3m.es (J.L. Rodríguez-Amenedo), arnalte@ing.uc3m.es (S. Arnaltes), marodriguez@eps.mondragon.edu (M.A. Rodríguez).

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requirements of communication and measurements that must be fulfilled.

Likewise, the Spanish TSO has proposed that when several wind farms evacuate energy in a common point of the transmission network only one mediating body (usually the owner with more power connected) there must be between the TSO and the rest of wind farm owners.

The functions of this new figure named connection point manager (CPM) are mainly to be in charge of operation and management of all of the power evacuated at that point and to be the only speaker (intermediary) with the TSO. This proposal has been discussed extensively since it would mean that CPM assumes the responsibility for operating the energy of all of the wind farms when, in fact, some of the owners could be competitors.

Apart from this important question, the technical consequences of assuming the coordinated operation of different wind farm concepts, as a CPM, are a challenge since the control capabilities are strongly dependent on wind farm technologies. At present, modern variable speed wind turbines (VSWT), are capable to exchanging reactive power with the grid and reducing active power by using pitch control systems and dynamic torque control on the electrical generator. However, older technologies, with many farms in operation, do not have these capabilities. This would not be an obstacle if additional electrical system compensators are used, mainly for reactive power and voltage regulation. In the case that active power limitation is required, it would be possible to disconnect wind turbines.

An additional problem associated with coordinated control of wind farms connected to the same point of the transmission network is that technical rules and operational procedures have not been developed yet.

There is not an extensive bibliography related to operation and control of wind farms. It has only been in the last few years that this topic has been considered of interest to the TSO, wind turbine manufacturers and researchers. Nevertheless, it is well documented that the first large offshore wind farm built in Denmark, Horns Rev, was designed to cope with all requirements of power control, frequency, voltage, protection, communication, verification and testing established by ELTRA (one of the Danish TSO [5]). According to those requirements, this wind farm is able to contribute to control task on the same level as conventional power plants, constrained only by the limitations imposed by the existing wind conditions [6].

Another example of integrated control systems was published in [7] for a wind farm located in Spain. In this article a supervisory control of active and reactive power control with a subordinate voltage control loop was proposed. In [8], a novel strategy for optimizing the active and reactive power set point in each wind turbine taking into account wind park internal losses was presented. Some other papers have been published recently. Specifically, in [9], the control possibilities provided by different technologies are described. Two of the wind farm concepts use active stall controlled wind turbines, one with AC connection and the other with modern HVDC/SVC connection of the wind farm. The third concept is based on pitch controlled wind turbines using a doubly fed induction generator (DFIG), which is practically the only technology presented for operation and control of wind farms in the reviewed bibliography.

Each wind farm concept has been researched separately, but the question is if a cluster of wind farms of different technology could be controlled and operated jointly from common system operator requirements on the point of interconnection (POI).

This research has been carried out in order to answer this question and to prove the real possibilities of a co-ordinated operation of wind farms with different technologies.

The paper is organized as follows. First, the technical specifications of the Spanish TSO will be described. In the second part, the electrical configuration is briefly presented. Then, the hierarchical control levels are explained and the performance of the control strategy is assessed and discussed by means of simulations. Finally, the control strategy is compared when for the fixed speed wind farm (FSWF) on load tap changer transformer and centralized compensation is used or not.

2. Spanish TSO grid code recommendations

The control of voltage and reactive power on the POI is designed from the TSO to enhance system stability and increase the capacity of the transmission system. In the Spanish case, the ancillary service of voltage control specifies that each generator must provide their respective reactive power capability so that voltages at some buses of the transmission network could be set by the TSO.

The reactive power capability of generators as a function of voltage according to this ancillary service is shown in Fig. 1. It should be noted that a regulation band of $\pm 15\%$ of reactive power capability over the active power, (Q/P) at rated voltage is considered. If the voltage is lower than 0.95 p.u. the generator must be able to provide $+30\%$ of Q/P or -30% of Q/P (reactive power absorbed) when the voltage is over 1.05 p.u.

However, effective voltage control depends on the short-circuit power at the connection point. The voltage band in the interconnection point (Δu), could be calculated as a function of the wind power penetration level (P/S_k), the network impedance phase angle (ψ_k) and the reactive power interchange with the grid in relation to the active power produced (Q/P). S_k indicates short-circuit apparent power of grid. Eq. (1) shows the voltage change as a function of the previous variables:

$$\Delta u(\%) = \left(\frac{P}{S_k}\right)(\%) \cdot \left(\cos\psi_k + \frac{\sin\psi_k}{100} \cdot \left(\frac{Q}{P}\right)(\%)\right). \quad (1)$$

If the resistive component of the grid is considered negligible ($\psi_k = 90^\circ$), as is a common practice in high