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Participation of wind power plants in system frequency control: Review of grid code requirements and control methods

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ABSTRACT

Active power reserves are needed for the proper operation of an electrical system. These reserves are continuously regulated in order to match the generation and consumption in the system and thus, to maintain a constant electrical frequency. They are usually provided by synchronized conventional generating units such as hydraulic or thermal power plants. With the progressive displacement of these generating plants by non-synchronized renewable-based power plants (e.g. wind and solar) the net level of synchronous power reserves in the system becomes reduced. Therefore, wind power plants are required, according to some European Grid Codes, to also provide power reserves like conventional generating units do. This paper focuses not only on the review of the requirements set by Grid Codes, but also on control methods of wind turbines for their participation in primary frequency control and synthetic inertia.

Contents

1. Introduction

For the stable operation of an electrical network, system frequency control is decisive. It ensures a continuous adaptation of power generation to power consumption. The power balance in

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the electrical network is interrelated to the network frequency via all synchronous generators connected to it; e.g. an increase in the load decelerates the synchronous generators and thus leads to a frequency drop. As frequency is uniform throughout the interconnected network, it is convenient to use it as a control variable for a decentralized control system: the network frequency control. It makes use of the power plants in the network, which – according to their abilities and agreements – adapt their active power feed-in according to the current system requirements. Thus, the power plants involved require a certain level of active power reserves. Traditionally and still typically, it is conventional generation plants, like hydroelectric and thermal power plants, which are used for frequency control. The ability of a system to maintain its frequency within a certain tolerance band is called frequency stability.

Another important function of conventional power plants for frequency control is the passively provided so-called *instantaneous power reserve*. Any imbalance between power generation and consumption is instantaneously balanced due to the physical principle of the synchronous generator. The large inertia of the rotating generator set works as a buffer storage, any usage leading to the mentioned change in rotational speed and thus in system frequency. The larger the synchronized inertia in the system, the slower the change of frequency [1].

The stepwise replacement of conventional generating units by wind and photovoltaic power plants will have a significant impact on the system frequency behavior. First, the grid loses the active power reserves of conventional plants. And second, it loses instantaneous power reserves, because wind turbine generator sets are operated decoupled from system frequency, which allows for aerodynamically efficient operation. In detail, the turbine's synchronous or asynchronous generators are connected to the grid via fast controlled power electronics [2–4].

The studies by the Irish regulator set out that system frequency stability could be compromised with 60–70% of the total instantaneous power generated from wind power plants [5].

In order to maintain system frequency stability in a network with an increasing share of wind power, wind turbines will have to take on more and more tasks of conventional power plants related to frequency control. This is reflected by a gradual development of more stringent requirements by system operators in regard to the integration of wind power plants into network frequency control [6]. According to some system operators, e.g. the Irish operator [7], wind power plants are already required to provide power reserves. Also, future regulations will appear with the development of new requirements regarding synthetic inertia by wind power plants [6].

Even though the power output of wind turbines depends on the unreliable and difficult-to-predict wind speed and the generator set does not provide a passive instantaneous power reserve, there are methods for wind power plants to actually provide power reserves and thus to participate in grid frequency control. Such abilities will be crucial for the successful integration of wind power plants into the grid.

This work presents a review of selected European Grid Codes and future trends regarding the tasks of wind power plants related to participation in frequency control. It also offers a literature review of the proposed methods for enabling wind turbines to provide active power reserves. Furthermore, the possibilities of wind turbines to provide instantaneous reserves are discussed.

2. Review of European Grid Codes regarding participation in frequency control

Due to the island situation of Ireland and the UK, frequency control is a particularly challenging task in these electrical networks since they do not have access to the large power reserves in the interconnected network of continental Europe. Thus, requirements for wind power plants are significantly stricter in these networks than in the continental grid. However, the rising share of wind power will also lead to stricter requirements in continental Europe.

Accordingly, this section firstly gives the definition and nomenclature for different types of active power reserves. Secondly, deployment times of power reserves for selected European grid codes are depicted. Then, particular requirements for wind power plants regarding frequency control according to the grid codes of Ireland and the UK are presented. Finally, future trends based on the latest ENTSO-E's Network Code [6] are discussed.

2.1. Nomenclature and definition of power reserves

Power reserves can be defined as the additional active power (positive or negative) that can be delivered by a generating unit in response of a power unbalance in the network between generation and consumption. Four different reserve levels can be defined: *instantaneous, primary, secondary and tertiary power reserves* [11]. This terminology is widely accepted; however nomenclature can vary from one country to another. The following contents provide the definition of each power reserve.

The *instantaneous power reserves* refer to the physical stabilizing effect of all connected synchronous generators due to their inertia. In the event of a generation drop in the network, the instantaneous reserves balance the power due to this stabilizing and passive effect. Their electrical power P_{elect} rapidly increases, which provokes an electromechanical unbalance in the generator set according to

$$P_{mech} - P_{elect} = J\omega_g \frac{d\omega_g}{dt}, \tag{1}$$

P_{mech} being the developed mechanical power by the generator, J is the moment of inertia referred to the generator shaft and ω_g is the mechanical speed of the generator (the electrical rotational speed of the generator ω_r is deduced from the number of poles p and ω_g as

$$\omega_r = \omega_g \frac{p}{2}. \tag{2}$$

As a result of the power imbalance, the rotational electrical speed ω_r decreases. This reduction is also in the interrelated frequency of the system. The rate of change of system frequency (ROCOF) depends on the amount of available instantaneous power reserves and thus on the inertia of the system [3]. Low levels of system inertia, i.e. high levels of ROCOF, can provoke the tripping of sensible loads, generating units and relays (implemented to avoid islanding [5]), thus affecting system frequency stability.

For power system related studies, it is a common practice to define the inertia constant H. The inertia constant, in seconds, determines the duration in which the generating unit theoretically may provide its rated power only using the kinetic energy stored in its rotating parts. It can be mathematically expressed as half of the mechanical acceleration time constant τ_{acc} (in seconds),

$$H = \frac{1}{2}\tau_{acc} = \frac{1}{2} J \frac{(\omega_g^{nom})^2}{P_{nom}^{total}}, \tag{3}$$

where ω_g^{nom} is the nominal mechanical generator speed in rad/s, P_{nom}^{total} is the nominal power of the generating unit, and J is the moment of inertia in kg m^2, referred to the generator shaft. The reader is referred to [1] and [15] for further details regarding the definition of inertia constant. It is important to note that wind turbines do not have inertia from the electrical system point of view, since the rotor is not synchronized with the network but connected through power electronics. According to [3], ROCOF