

Grid Inertia and Frequency Control in Power Systems with High Penetration of Renewables

Pieter Tielens, Dirk Van Hertem

Abstract—With increasing power generation out of renewable energy sources, there is a rising interest to investigate their impact on the power system and its control. In this paper, both the impact on frequency control and the capability to deliver frequency support by renewables is presented. A test grid is used to also investigate the variation of system inertia as a function of time. It is shown that by integrating renewables in the generation mix, the frequency support deteriorates, but through additional control, the frequency support can be improved. Finally the control of an inertialess grid is shortly described and some recommendations for future research are given.

Index Terms—power-frequency control, renewable energy integration, grid inertia

I. INTRODUCTION

At the start of 2011, after a decade of significant growth, the installed wind and solar power in the EU-27 countries reached a capacity of respectively 86 GW [1] and 29 GW [2]. To meet the 2020 targets of the European Union, the installed capacity of renewable energy sources (RES) is expected to increase even further.

While already dealing with aging infrastructure and an ever increasing demand for electric power, this projected increase of electric power coming from renewable energy sources will put an even higher stress to the already highly loaded power system.

From a power system perspective, this dispersed renewable electricity generation behaves quite different from traditional, centralized generation facilities. Apart from their intermittent nature, most of these sources do not contribute to system reserves and to the total system inertia. This system inertia is often considered as one of the vital system parameters upon which the synchronized operation of current day power systems is based: the inertia in the rotating masses of synchronous generators and turbines determines the immediate frequency response with respect to inequalities in the overall power balance. When a frequency event occurs, the synchronous machines will inject or absorb kinetic energy into or from the grid to counteract the frequency deviation. The lower this system inertia, the more nervous the grid frequency reacts on abrupt changes in generation and load patterns.

Wind turbines are generally equipped with back-to-back converters, in the form of doubly fed induction generators (DFIG) or full converter synchronous generators (FCSG), which electrically decouple the generator from the grid. Therefore no inertial response is delivered during a frequency event,

although a lot of kinetic energy is stored into the blades and the generator. Unlike wind turbines where there is actually some kinetic energy available (although rarely used), solar panels are virtually inertialess.

The paper is organized as follows. Section II elaborates the impact of replacing conventional power plants with renewable energy sources on frequency control. Next, in section III, a small power system is used as a test case to investigate both the variation of system inertia during the day as well as the influence of integrating renewables on the system inertia. Section V deals with inertialess grids. Finally, section VI gives some recommendations for future research and section VII resumes the main conclusions.

II. IMPACT OF RENEWABLE ENERGY SOURCES ON FREQUENCY CONTROL

The frequency control in a power system can be roughly split up into two phases. In a first phase, the frequency controllers of the power plants have not yet been activated. The generators will absorb or release their kinetic energy to arrest the change in frequency. This phase is called inertial response, because the inertia dampens the frequency changes. In a second phase, the frequency is first stabilized and then restored to the nominal frequency by respectively the primary control (governor action) and secondary control [3], [4]. Additional measures, like automatic load shedding, can be taken in case of severe frequency deviations. In the following sections, the impact of integrating renewables on both phases is described.

A. Inertial response

Focussing on the inertial response, the frequency variation, directly after a significant generation-load imbalance is determined by the equation:

$$P_g - P_l = \frac{d \left(\frac{1}{2} J_{system} \cdot \omega_{cl}^2 \right)}{dt} \quad (1)$$

with P_g the generated power, P_l the power demand, ω_{cl} the electrical angular frequency and J_{system} the inertia of the system. The right-hand side of equation (1) is the derivative of the kinetic energy stored in all the generators of the power system. The kinetic energy stored in a single generator shaft is often expressed proportional to its power rating and is called the inertia constant H_{gen} :

$$H_{gen} = \frac{S_{gen} \cdot \omega_{cl,0}^2}{2 \cdot S_{gen}} \quad (2)$$

With S_{gen} the nominal apparent power of the generator, $\omega_{cl,0}$ the nominal system frequency and p the number of pole

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