Impact of Converter-Interfaced Generation to the Frequency Response of the European Power System

Rossano Musca
University of Palermo, Italy

Luigi Busarello
NEPLAN AG, Switzerland

Abstract*—The increase of converter-interfaced generation (CIG) typically related to renewable energy sources is progressively causing a significant change of power systems operation. The curtailment of synchronous generation with the consequent reduction of the overall kinetic energy is one of the related issues, currently under investigation in academia and industry. The work considers the problem of overall inertia reduction from a large-scale point of view, analyzing the impact of different CIG integration levels to the frequency response of the power system of Continental Europe. The kinetic energy is evaluated for each country of the synchronous area, and the system is modified substituting conventional synchronous generation with converter-interfaced generation. The models of power converters and corresponding controls follow typical representation for stability studies: they are modeled as controlled current sources with active and reactive power control loops, implemented as user-written equations within the overall mathematical model of Continental Europe power system. Comprehensive time-domain simulations are performed for each scenario, assuming the system subjected to a power plant outage: the obtained frequencies for Western, Central and Eastern Europe are reported, and typical frequency metrics are used to evaluate the response of the system across the different scenarios. Results show how the penetration of CIG affects the frequency response of the system, in terms of instantaneous frequency deviation and maximum frequency rate. A significant change in the inter-area oscillations is also observed, with a progressive increase of the oscillation frequency of the East-West mode, as confirmed by the modal analysis of the system.

***Keywords*— converter-interfaced generation; Continental Europe; dynamic analysis; frequency response; low inertia.**

I. INTRODUCTION

The constant increase of renewable energy sources (RES) penetration within power systems is leading to the dismissal of conventional, fuel-based power plants. The amount of synchronous generation (SG) is progressively reducing, while the amount of converter-interfaced generation (CIG) is increasing. The expected trend for the power system of Continental Europe (CE) is a strong synchronous generation curtailment as the RES penetration increases, with a consequent significant reduction of the overall kinetic energy available. While rotating machines directly connected to the grid provide inertia to the system, RES power plants are typically interfaced to the system via full-scale static power converters, and therefore they do not provide spontaneously inertial response. The paper addresses the issue of overall inertia reduction in the Continental Europe considering the large-scale dynamic model of the system: the power system is simulated under the assumptions of high penetration of CIG power plants, in substitution to conventional SG power plants. The system is analyzed in three different scenarios, respectively corresponding to increasing level of CIG integration in the system. The synchronous machines to be substituted with CIG power plants are selected per country, according to a specific methodology and the considered RES penetration level. The converters are implemented as user-written model equations, using the proprietary modeling language of power system analysis software: the models represent the converter as controlled source, with active power and reactive power control loops, synchronous rotation frame and phase-locked loop blocks. The system is then simulated in perturbed condition, assuming a generator outage in the western part of Europe. The response of the system is assessed using typical frequency metrics such as the minimum frequency after the perturbation (frequency nadir), the maximum rate of change of frequency (RoCoF) and the frequency deviation at steady-state. The system is analyzed both with time-domain and modal analyses.

II. OVERVIEW

The interconnected synchronous CE power system includes 26 countries and it is the largest interconnected system in the world. The model of the CE interconnected system for performing dynamic studies and analyses has been prepared by ENTSO-E System Protection and Dynamics (SP&D) experts. The implemented system consists of over 20’000 nodes and over 1’000 synchronous machines, 900 of them being equipped each with voltage regulator, turbine-governor and power system stabilizer (PSS). This model is first implemented and validated in the software NEPLAN. Then, the model is properly modified to account for the integration converter-interfaced generation power sources, as replacement of a given percentage of synchronous machines. The application of a specific integration methodology allows the modification of the CE power system, with the selection of the synchronous machines to be substituted. The methodology is performed according to the kinetic energy contribution (Figure 1) and the CIG integration level of the considered scenario. The CIG sources are represented as controlled current sources, with active and reactive power control loops, synchronous rotation frame and PLL: this representation is a regular approach to model generation sources interfaced to the grid through full-scale power converter for dynamic analysis. Methodology and CIG dynamic model are described in the paper. The simulations results for the investigated scenarios are summarized in the frequency metrics reported in Table I.

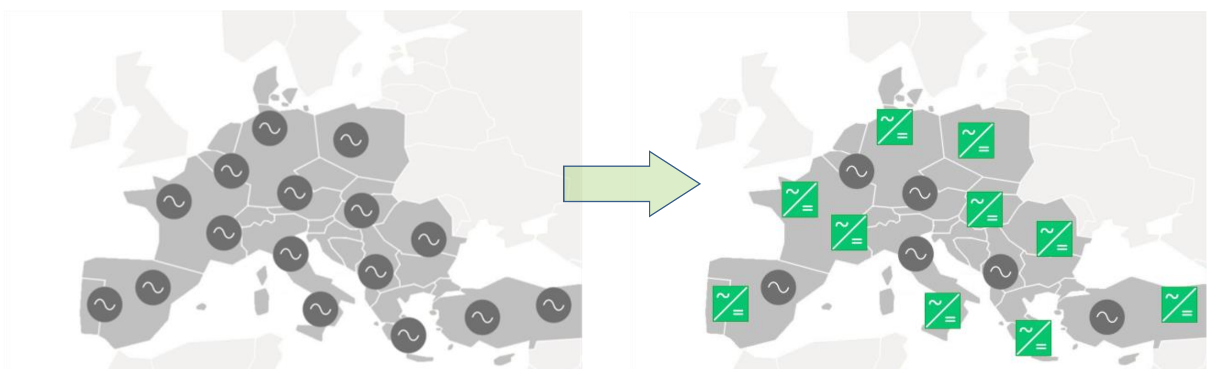

Fig. 1. Converter-interfaced generation integration in the CE power system.

TABLE I. FREQUENCY RESPONSE RESULTS

Scenario	**Frequency response metrics for the simulated scenarios**			
	Frequency nadir (Hz)	***RoCoF (mHz/s)***		***Frequency deviation (mHz)***
		max	***500 ms***	
0%	49.96	-80.7	-52.9	-27.7
30%	49.95	-91.4	-63.6	-35.4
60%	49.92	-224.5	-117.2	-44.0
90%	49.88	-640.5	-173.5	-74.6

The particular impact of CIG integration on the inter-area oscillations of the CE synchronous area is also recognized and addressed in the paper. Both time-domain and modal analysis results are reported: the characteristics of the transient response are commented and analyzed, and a physical explanation of the observed phenomena is provided.