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Current procedures and practices on grid code compliance verification of renewable power generation

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ABSTRACT

Generation assets applying for grid connection must comply with certain grid code requirements. Grid code compliance verification shall include revision of documentation covering technical data and models, checking of requested capabilities, and validation of model performance. These procedures are singular regarding renewable power generation, due to their technical characteristics, specific topologies and short experience. This paper aims to carry out an updated review of the international regulations and current practices regarding the verification and certification of the electrical performance in renewable generation systems. Grid code compliance can be verified by practical tests or by simulation of validated models. Therefore, this paper also encompasses modelling and validation requirements, highlighting challenges caused by current procedures.

1. Introduction

Grid codes specify the electrical performance that generation assets must comply with in order to obtain the required approval for its connection to a grid. Demonstrating grid code compliance and achieving a grid connection agreement are, therefore, essential milestones in the development of a power plant project. The increasing penetration of renewable generation plants formed by a large number of individual generating units poses a challenge to system operators, in terms of technical singularities, connection process and plant modelling management. In order to cope with these issues, specific compliance procedures based on testing and simulation have already been established for Renewable Energy Sources (RES). The present paper introduces current procedures and practices on grid code compliance verification for renewable power generation.

Grid code compliance verification has a double objective. On the one hand, plant owners are responsible for demonstrating compliance of the grid code to the relevant network operator. And, on the other hand, network operators have to assess the compliance in order to ensure that the new plant will not adversely affect the secure operation of the power system. A grid code should be complemented by a good verification plan, in order to avoid misinterpretations of the requirements. According to ENTSO-E [1], compliance testing is defined as the process of verification that power generating facilities comply with the specifications and requirements provided by this grid code. It can be carried out before starting operation of new installations. The verification should include the revision of documentation (including technical data and models), the verification of the requested capabilities of the facility by practical tests and simulation studies and, finally, the validation of the model performance based on actual measurements. The grid code compliance shall be maintained throughout the lifetime of the facility. Hence, power plants shall undergo periodical compliance monitoring processes, in order to verify that their technical capabilities are maintained and simulation models are still valid.

A grid code verification plan is as important as the regulation itself and it should not need to leave room for interpretation regarding how each requirement shall be assessed. Unfortunately, not every grid code is complemented by a clear and detailed compliance verification plan. Grid code evolution has been extensively studied in the literature, mainly focused on technical requirements for large Wind Power Plants (WPP). Several reviews including thorough analysis and comparison of grid codes were conducted in last years, due to the continuous revisions of regulatory frameworks, such as [2–13].

Tsili et al. conduct a comprehensive review including relevant European Transmission System Operators (TSOs), several operators in Canada, the Federal Energy Regulatory Commission (FERC) regulation in US and New Zealand in [2]. Reference [3] compares regulation for wind farms in European countries such as Denmark, Germany, Spain, UK and

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Ireland, along with the technical rules in China. Mohseni and Islam study countries with significant wind power penetration, such as Denmark, Germany, Spain, UK, Ireland, US, Canada or Nordic countries in [6]. Ref. [8], focused on wind power integration in Europe, not only does it compare national specifications, but it also mentions grid code compliant wind generation technologies. Diaz-Gonzalez et al. present a review of selected European grid codes and future trends regarding the participation of WPPs in frequency control in [9]. Singularities of the regulatory framework for renewable energy sources in weak and isolated power systems are analysed and compared in [10,12], including New Zealand, Ireland, UK, Denmark, insular territories in France and Spain, and Australia. Requirements for ensuring transient stability and frequency regulation prove to be critical in these power systems. [13] discusses the advanced grid code requirements for the integration of large scale photovoltaic power plants in the transmission system, given the expected growth in PV installed capacity in next years. The paper compares technical requirements to be met by PV installations in Germany, China, Romania, Puerto Rico, US and South Africa. On the whole, literature has mainly analysed technical requirements to be met by large renewable power plants.

However, grid code compliance verification remains a major open issue, as pointed out by [2]. In the regulatory frameworks, grid code verification as well as generation unit and system certification procedures are still at an early stage. Literature related to regulation verification and certification aspects is sparse, scattered or focused on a single country [4,14]. Often, it can also be found within grid code reviews [6,15], even for distributed generation [16]. Several testing methods for compliance verification have been proposed in [17–20]. Regarding conformity verification through simulation techniques, a review of modelling and simulation requirements for variable generation in the grid codes would also be useful [21]. Previous works can be found in [22–24].

Therefore, this paper aims to fill the gap and carry out an updated review of the international regulations and current practices regarding the verification and certification of the electrical performance in renewable generation systems. Compliance verification can be carried out by testing and simulation techniques. Hence, this paper introduces requirements regarding modelling and model validation in the first place. Modelling issues are highlighted in the paper, including: specific challenges involved when modelling renewable power plants, use of RMS or EMT models, and the conflicting perspectives of operators and manufacturers regarding the disclosure of power plant models. Model validation consists of three main steps: data collection, simulation and the acceptance of the model validity. The paper includes the most usual approaches for accomplishing each step. Finally, the paper reviews the current practices in selected countries to verify the compliance with technical requirements, such as voltage and frequency control, active and reactive power control, frequency response or Low Voltage Ride-Through (LVRT).

The present study is a continuation of the work presented by the authors in [10]. Therefore, the countries under analysis are Australia, Denmark, Germany, Ireland, New Zealand, Spain and UK. The selection covers European countries with a significant penetration of RES and pioneering regulation frameworks. Among them, Ireland and UK are insular territories with weak interconnections, where transient stability and frequency regulation can be critical. New Zealand also belongs to this category and, in Australia, wide parts of its power system are weakly linked. So, the point of connection of large RES power stations will have low short-circuit values. This way, for a more insightful analysis, this paper includes a broad spectrum of countries with contrasting power system structures, RES penetration degrees and network strength values.

This paper is organised as follows. Section 2 describes and compares renewable power generation asset modelling and simulation requirements, reviewing most challenging aspects. Simulation models must be accompanied by validation tests to show the validity of the models. Model validation practices and practical set-ups are indicated in Section 3. Finally, procedures to verify the conformity of RES installations with technical requirements (including voltage and frequency control, active and reactive power control, frequency response and LVRT) are analysed in Section 4, with special emphasis on certification procedures in Spain and Germany. Section 5 presents the conclusions of the study.

2. Renewable power generation modelling and simulation

According to ENTSO-E [1], system operators may require generating unit models for both steady state and dynamic simulations (50 Hz component) as well as for electromagnetic transient simulations, where appropriate and justified. Model format must also be provided, and model structure and block diagrams shall be documented. Regarding dynamic simulations, models shall contain submodels of alternator and prime mover, speed and power control, voltage control, protection and converters. Thus, system operators have introduced specific conditions for the inclusion of power plant models and simulation procedures to be followed by manufacturers, in order to check the viability of the installation and the conformity with grid code rules.

Grid code requirements regarding data, modelling and simulation have been previously reviewed in [22,23]. [22] gathers practices by several system operators regarding modelling requirements, ranging from Argentina, where non-confidential and non-black box models are required for all WPPs above 10 MW, and Croatia, where no generator model is required before connecting a generator. However, the enquiry was carried out in 2005, and since then, modelling requirements have evolved. Therefore, requirements regarding modelling and simulation in the countries under study have been described and compared in this section, including the application scope, model characteristics, and simulation requirements.

Table 1 indicates the documents containing modelling and validation prescriptions required by system operators for renewable generation. Regulations are often complemented by guidelines with a more specific explanation. This is the case for most of the countries under study. Regarding generation assets, several approaches are used in the regulation under review: technical regulation in Australia and New Zealand is technologically neutral; Ireland has separate specifications for wind power, whereas in Denmark both wind and PV power must meet specific requirements; and finally, in UK and Spain requirements not only apply to wind power but also to other intermittent energy technologies.

Modelling issues for RES are analysed below. Table 2 summarises and compares modelling and simulation specifications in the countries under study in the present paper.

2.1. Challenges regarding renewable power generation modelling

In the traditional power systems, it was not necessary to include renewable power generation models in dynamic simulations, because penetration was still low. Thus, disconnection of renewable generating units during disturbances was a usual practice. Nowadays, situation has changed and many grid codes require manufacturers and generators to supply valid dynamic models. However, several challenges have been reported in the literature regarding renewable power generation modelling [42,43]:

- Generators are usually based on power electronic devices. Thus, modelling can pose some issues, especially regarding control systems and algorithms that are often proprietary.
- Available models typically represent only large signal performance, but the impact of wind farms on small signal performance needs also to be assessed.
- Performance under unbalanced network conditions, caused by unbalanced faults or asymmetric line impedances and loads, can significantly impact power electronic control systems, and making it