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Electrical machines-based multi-disturbance device for testing distribution grid technologies

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ABSTRACT

The growth of distributed energy resources in power systems, mainly converter-coupled generators, has forced the evolution of grid codes, increasing the requirements to be fulfilled by the generators before their connection to the mains. Solving this problem is crucial to guarantee the reliability and stability of the power system. Current standards force the generators to remain connected when facing voltage and/or frequency disturbances and, in some advanced grid codes, also when the generators are facing transient phase jumps produced as a consequence of those disturbances. If considering that the increment of the distributed generation is mainly done at a distribution level, it is unrealistic to consider voltage and frequency events as decoupled phenomena in the testing and certification procedures, as it is currently done. The testing device proposed in this paper is able to reproduce voltage, frequency and phase jumps disturbances of a controlled value simultaneously, being able to reproduce the real grid behavior reliably. Its design is based on standard components with a simple control system, which makes it easily replicable and scalable up to the power of the device to be tested. Therefore, the proposed device is an interesting commercially competitive testing equipment suitable for certification.

1. Introduction

Owing to the increasing integration of renewable energy sources (RES) in electrical power systems, it was necessary for the system operators to adapt current grid codes, thereby establishing new and stricter requirements to be fulfilled for connecting the generators to the electricity networks. These standards lay down reference disturbances under which the sources have to remain connected. The disturbances are usually voltage dip/swell patterns or frequency disturbances (steps or ramps) and in some new and more advanced codes, they are even incorporating phase jump requirements [1]. The voltage dip profiles are usually defined as the envelope curves of all voltage dips registered over a given period in the electrical network where the code is going to be applied [2]. This variety of grid disturbances introduces the necessity of flexible testing equipment being capable of reproducing variable patterns, with the aim to certificate the capabilities of all converter-coupled RES before their connection to the grid. For example in the Spanish system, connection requirements are nowadays already very demanding for wind power generators [3] due to the huge amount of installed wind power capacity—approximately 22% of the total capacity-23.057 MW in 2016 [4]. Such tough voltage dip compliances are still not required in most countries, neither for wind nor for other energy sources. However, in the near future the connection of these technologies to the grid will also be committed to compliance with equally tough requirements, because the European ENTSO-E Network Code on Requirements for Generators (RfG) has been recently approved (May 2017). This code forces the grid operators to implement the standards in their countries in less than three years [5].

On this basis, a novel testing device for RES certification is presented in this paper. Its main advantage, which makes it unique among all the existing testing equipment [6] is the capacity to simultaneously reproduce voltage, frequency and phase jump disturbances with an electrical machines-based topology, covering all the requirements demanded by current and expected grid codes (following the ENTSO-E guidelines). The lack of power electronics avoids additional harmonic pollution on the mains. Further, the proposed equipment is also a flexible, cheap and easily scalable device. It is very appropriate for field testing, because it is based on the use of asynchronous electrical machines. The device can be easily programmed to change the disturbances to be reproduced with simple operation through a designed human machine interface (HMI).

This paper is organised as follows: Section 2 reviews the main

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Nomenclature

Symbols and abbreviations

DER	distributed energy resources
EDG	electrical disturbances' generator
EUT	equipment under test
HMI	human machine interface
HVRT	high voltage ride through
IGBT	insulated gate bipolar transistor
LVRT	low voltage ride-through
PCC	point of common coupling
PLL	phase locked loop
RES	renewable energy sources
RfG	requirements for generators
RTI	real-time interface
SCR	silicon controlled rectifier
VFT	variable frequency transformer
ZVRT	zero voltage ride through

topologies of different testing devices suitable for RES certification both at a technical-literature and commercial level, highlighting the main differences between them and the testing device proposed in this work. In Section 3 the device and the operational procedure for test execution are described. Section 4 shows the implementation of an initial prototype at laboratory scale. In Section 5, the testing device performance is analysed, showing different disturbances that the equipment is able to reproduce. Finally, in the last section, the main conclusions of the paper are presented.

2. State of the art of current equipment for testing distribution grid technologies testing

Owing to their significance explained in Section 1, topics related to the certification process and the devices required for testing and validating electrical generators before their connection to the grid have been broadly addressed for several years.

Most of the testing devices proposed today in technical literature and patents focus on different devices that are able to reproduce voltage dips/swells. Voltage dips are the most severe disturbances that a grid-connected device can experience. In the recent past, these events were responsible of the massive disconnection of primitive wind power plants based on squirrel-cage induction generators [7,8]. Recently, the widespread installation of distributed energy resources (DERs) into the distribution grid, which is weaker than a transmission grid, has forced the evolution of more demanding grid requirements.

There exist three main topologies of electrical disturbance generators (EDG) commonly found in literature: topologies based on impedances, on electrical machines (both static and rotating) and on power electronics converters.

2.1. Impedance-based EDG

Impedance-based EDG have been the most widely used due to their simplicity and robustness. However these generators are only suitable for testing low-voltage ride-through (LVRT) and high-voltage ride through (HVRT) capabilities of the equipment under test (EUT). In [9] the most extended setup for the impedance-based topology (shown in Fig. 1) is analyzed. The insertion of an impedance in parallel, named Z_g, at the point of common coupling (PCC) establishes an alternative current path, thereby creating a sudden voltage dip with adjustable depth that depending on the impedance value. These devices are scalable up to the EUT power. Owing to their configuration it is necessary to adjust or change the impedances for the different voltage depths, thereby making them an unadaptable testing setups. With the implementation of an ad hoc control of the electromechanical or static contactors the devices are able to generate single-phase, two-phase or three-phase dips. In [10], the impedances in the EDG device studied belong to a three-phase transformer and are also further employed for reproducing single-phase, two-phase and three-phase faults. However, the equipment maintains the classical T-configuration. This device could be considered as enclosed within the first group.

This configuration is required in LVRT/HVRT testing of wind turbines according to the international IEC 61400-21 standard [11]. In Spain, it is also the demanded configuration for testing and validating the behaviour of wind turbines and PV installations according to [12]. The main drawback of this topology is the influence that the series impedance of the testing device (Z_s) imposes on the EUT dynamics. In order to minimise this effect, the regulation establishes that in case of a short-circuit power at the PCC below 5× the EUT power and the voltage dip profile must be obtained at the PCC through a test with the EUT loaded. Otherwise, the reactance can be adjusted in a no-load test and considered suitable for the test cases with load. Despite its limitations, this is still the most common topology used by manufacturers, such as Enercon or Gamesa, in accordance with the IEC standard. The certification of their 5 MW wind turbine series is accomplished in the Wind Turbine Test Laboratory (LEA) of the Spanish National Centre for Renewable Energy (CENER) [13,14].

2.2. Electrical machines based EDG

Electrical machines-based EDG devices use as main element an electric machine, either static or rotating. Most of the testing equipment uses the combination of transformers with any kind of electronic power modules, such as SCRs or IGBTs [15,16] as shown in Fig. 2.

As main advantage to highlight, these devices are easily scalable, because the transformers and power electronic modules exist commercially up to the voltage and power levels that would be required by the DERs to be tested. In order to make the testing device more flexible, usually tapped transformers are employed to check several voltage dip patterns. Ref. [17] uses a combination of a tapped transformer. With tap inductances, and with this configuration, the device can test EUTs up to 10 MW. The main advantage of these systems is that they are able to generate voltage dips, frequency disturbances and phase jumps, as the EDG device proposed in this paper. However, it cannot reproduce all of them simultaneously. Within the electrical machines-based group, only two EDG devices appear in technical literature that were explored as devices using synchronous generators [18,19]. The synchronous generators present the advantage, over the simplest impedance-based ones, of being able to reproduce both voltage and frequency disturbances by adjusting field excitation and mechanical power of the turbine respectively. However, the scalability of these devices implies very high costs that make them unaffordable. This caused this topology

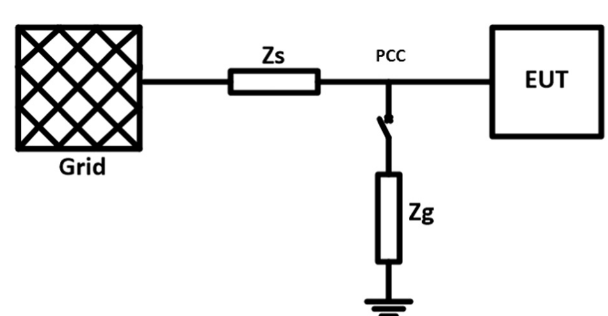

Fig. 1. Impedance-based voltage dip generators.