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Challenges of integrating renewable energy sources to smart grids: A review

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ABSTRACT

The deep penetration of renewable energy sources is on the cutting edge of smart grid vision. However, the variability and limited predictability of these sources have brought many technical challenges to grids. Many regulatory communities and system operators in the power sector have established grid codes to ensure proper connection of these renewable sources. This paper investigates the up-to-date methods used to enhance power system performance in the presence of a large share of renewable energy generation. In particular, two areas are addressed; the first is the techniques used for improving the wind and photovoltaic low-voltage ride-through capabilities to meet the required grid codes. The second is the contribution of these sources to the small signal stability of the power system in terms of inter-area oscillation damping.

Contents

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Nomenclature

BESS	: Battery Energy Storage System
DVR	: Dynamic Voltage Restorer
FC	: Fuzzy Controller
GSC	: Grid-Side Converter
HVDC	: High Voltage Direct Current
LVRT	: Low Voltage Ride-Through
DFIG	: Doubly-Fed Induction Generator
PCC	: Point of Common Coupling
PMSG	: Permanent-Magnet Synchronous Generator
PMU	: Phasor Measurement Unit
POD	: Power Oscillation Damping controller
PSO	: Particle Swarm Optimization
PV	: Photovoltaic
PVPP	: Photovoltaic Power Plant
RSC	: Rotor-Side Converter
SPMS	: Synchronized Phasor Measurement System
WADC	: Wide-Area Damping Controller
WAMS	: Wide-Area Measurement System
WG	: Wind Generator
WPP	: Wind Power Plant

1. Introduction

The smart grid heralds the coming era of new power systems that utilize advances in communications and information technologies to overcome the challenges of current power systems [1,2]. The smart grid is essential in ensuring high quality services, consumer engagement in consumption management, cyber and physical security of the system, system reliability, and integration of renewable energy sources into the grid [3,4]. Generation from renewable energy sources especially wind and solar photovoltaic is growing rapidly in preparation for the smart grid and also due to the fact that these sources are clean and sustainable [5]. The photovoltaic (PV) global cumulative generation has grown from 3 GW in 2003 to 139 GW in 2013 and is expected to reach 430 GW by 2018 [6]. The wind generation is growing faster than PV, increasing from 39 GW in 2003 to 318 GW in 2013, and is predicted to reach around 600 GW by 2018 [7].

The electric grid is significantly affected by the integration and deep penetration of renewable energy sources because of their variability [8,9]. A lot of challenges are initiated by this penetration, such as effective forecasting, energy storage management, demand management systems, voltage control, and power system stability [10–14]. This paper discusses the challenges of voltage control and system stability. Voltage control is a major requirement for power systems and many countries have developed methods of keeping renewable energy sources connected to grids in order to survive voltage dips. These renewable sources should ride-through faults and low voltage situations to avoid system cascaded failure [15]. Their ability to execute this is known as the low-voltage ride-through capability (LVRT). Regarding system stability, renewable sources can be utilized to enhance the power system's stability such as inter-area oscillation damping. The problem with oscillation is that it introduces additional instability to the system when abnormal situations occur and also limits power transfer capabilities, especially in long transmission lines. This paper will focus on reviewing inter-area oscillation damping techniques and LVRT capability enhancement methods in power systems involving PV and wind power plants (WPPs).

This paper is organized as follows: Section 2 reviews the LVRT requirements in grid codes and LVRT enhancement methods for both WPPs and PV power plants (PVPPs). Section 3 investigates inter-area oscillation damping techniques in WPPs and PVPPs. The conclusion will be presented in Section 4.

2. Low-voltage ride-through (LVRT) capability

The LVRT capability of WPPs and PVPPs is the ability of these sources to stay connected to grids during voltage dips [16]. This capability ensures system's post-fault stability and fast recovery. A few years ago, when renewable energy was not deeply penetrated in grids, flexible ac transmission system (FACTS) devices were used extensively to enhance the voltage profile [17]. Static var compensators (SVCs) and static compensators (STATCOMs) are usually connected to the point of common coupling (PCC) of WPPs to control voltage [18–20]. In other approaches, battery energy storage system (BESS) and electric springs are implemented for the better voltage control [21–23]. However, with the growing generation from renewable sources, these techniques faced many challenges for ensuring system stability. This situation obligated technical legislations for connecting renewable energy sources to grids which is known as grid codes.

2.1. LVRT requirements in grid codes

The grid codes are regulations set by power system operators to ensure proper functioning of all system components. Both WPPs and PVPPs have grid codes to regulate their connections to grids. According to grid codes, WPPs are required to survive system disturbances and also to provide ancillary services in order to ensure network stability [24]. These requirements or grid codes

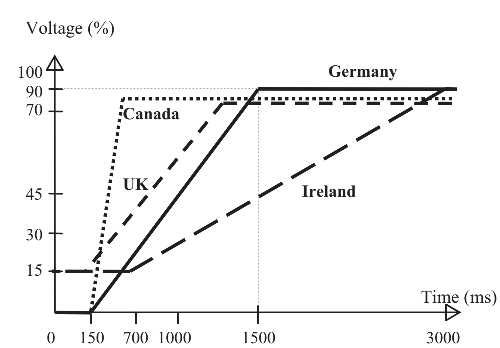

Fig. 1. Low-voltage ride-through requirements for wind power plants in different grid codes.

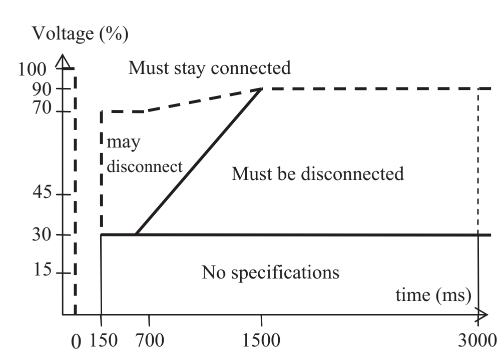

Fig. 2. Low-voltage ride-through requirement for photovoltaic power plants in the German grid code.