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A comprehensive review of low-voltage-ride-through methods for fixed-speed wind power generators

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ABSTRACT

This paper presents a comprehensive review of various techniques employed to enhance the low voltage ride through (LVRT) capability of the fixed-speed induction generators (FSIGs)-based wind turbines (WTs), which has a non-negligible 20% contribution of the existing wind energy in the world. As the FSIG-based WT system is directly connected to the grid with no power electronic interfaces, terminal voltage or reactive power output may not be precisely controlled. Thus, various LVRT strategies based on installation of the additional supporting technologies have been proposed in the literature. Although the various individual technologies are well documented, a comparative study of existing approaches has not been reported so far. This paper attempts to fill this void by providing a comprehensive analysis of these LVRT methods for FSIG-based WTs in terms of dynamic performance, controller complexity, and economic feasibility. A novel feature of this paper is to categorize LVRT capability enhancement approaches into three main groups depending on the connection configuration: series, shunt, and series–shunt (hybrid) connections and then discuss their advantages and limitations in detail. For verification purposes, several simulations are presented in MATLAB software to demonstrate and compare the reviewed LVRT schemes. Based on the simulated results, series connection dynamic voltage restorer (DVR) and shunt connection static synchronous compensators (STATCOM) are the highly efficient LVRT capability enhancement approaches.

Contents

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1. Introduction

Fortunately, the goal of reducing green-house gas emissions is aligned, to a significant extent, with the evolution and penetration of renewable energy sources (RES) [1]. The attempts to reduce the continued pollution are promising in view of the recent dramatic increase of installed wind turbines' (WTs) capacity [2–4]. However, grid integration of large WTs can pose serious adverse effects in weak or faulty grids [5]. The trend towards the integration of more WTs contributes to the increase in the fault current levels, as well as voltage reductions at the terminals of wind generators, which may lead to the disconnection of WTs, and consequently affects power system stability during and after fault clearance [6–8].

Recently, many power system operators in Europe and other regions of the world have begun expanding and modifying their interconnection requirements for wind farms through technical standards, known as grid codes [9,10]. One of the critical requirements concerning the grid voltage support is the low voltage ride-through (LVRT) capability, which is included in many new grid codes [11–15]. Fig. 1(a) shows a practical example of the LVRT curve defined by the Danish system operator (Energinet.dk) for WTs connected to the grid [16]. Based on this regulation, if the voltage remains at a level greater than 20% of nominal value for a period of less than 0.5 s, the WT should remain connected to the grid.

WTs are only allowed to disconnect from the grid when the voltage profile falls into Area B. Besides the LVRT requirements, some grid codes require large WTs to contribute to the voltage restoration of the power system by injecting the reactive power during the fault and the recovery period [17,18], while maintaining the operating point above the area of Fig. 1(b). A literature review on international grid codes for wind power integration has been discussed and summarized in [19–23].

Although most wind turbine generators manufactured today are doubly-fed induction generators (DFIGs) [24,25] and permanent-magnet synchronous generators (PMSGs) [26], a non-negligible 20% of the existing wind energy in Europe is still employing fixed-speed induction generators (FSIGs) due to their simple structure and lower maintenance cost [27,28]. Thus, the fault-ride through characteristics of FSIG-based wind turbines still need to be analyzed. However, this technology is unable to fulfill new grid code requirements since they have no power electronic converters to control terminal voltage and reactive power output. In this case, induction generators may suffer from a voltage instability problem, which is becoming a significant concern with large-scale wind farm penetration. Therefore, technical solutions must be developed in order to ensure that those wind farms fulfill grid code requirements for their operations.

In the recent literature, various studies have been individually documented in terms of installing additional supporting technologies to enhance the LVRT capability of the FSIGs-based WTs, which need to be properly reviewed and discussed.

Although there are a few valuable review papers of LVRT enhancement strategies for DFIGs and PMSGs-based WTs [29–31], up to the present time, as far as the authors are aware, there has been no comprehensive report, fully considering LVRT improvement methods of FSIGs based WTs. Ref. [32] only presented a brief review and comparison of the series compensators for LVRT enhancement of a wind generator system based on FSIGs.

The main contributions of this paper are organized into the following sections: after describing the operation of the FSIG-based WT under normal and faulty conditions in Section 2, the comprehensive review of the recently LVRT capability improvement approaches is discussed in Section 3. The reviewed methodologies are classified into the three main groups, namely, (i) series-connected solutions (i.e., thyristor-controlled series compensation (TCSC), dynamic voltage restore (DVR), series dynamic braking resistor (SDBR), magnetic energy recovery switch (MERS), and fault current limiter (FCL)); (ii) shunt-connected solutions (i.e., static var compensator (SVC), static synchronous compensator

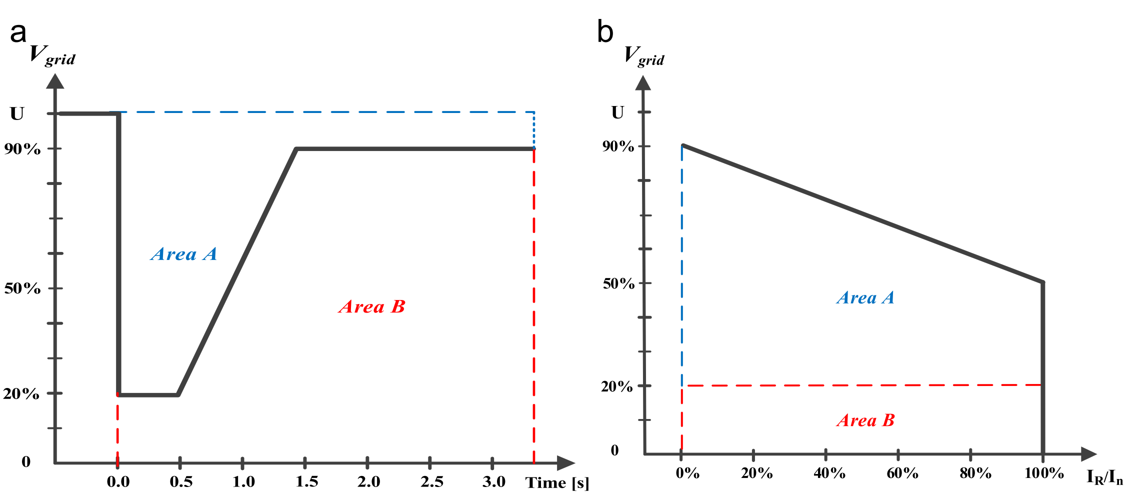

Fig. 1. Danish grid codes. (a) LVRT requirement. (b) Reactive power support requirement.