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A comprehensive review of low voltage ride through of doubly fed induction wind generators

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ABSTRACT

Wind power has become an important source of renewable energy in a number of countries around the world, including Denmark, Germany and Spain. Thereupon, connection of wind farms to the grid and their dynamic behavior under different grid conditions has become an important issue in recent years and new grid codes have been introduced. One of the most important issues related to grid codes is the low voltage ride through (LVRT) or fault ride through (FRT) capability of wind farms. Based on such code requirements, wind turbine generators must remain connected to the grid and actively contribute to the system stability during various grid fault scenarios that result in a generator terminal voltage dip. Moreover, wind turbine generators should have the ability to supply reactive power during the faults. In addition, they should supply active and reactive power immediately after fault clearance to support the network frequency and voltage, respectively. In this paper, a comprehensive review of researches published about analysis, modeling and improvement of LVRT of wind turbines with doubly fed induction generator (DFIG) is presented. The review also concludes that more investigations should be carried out to completely fulfill the grid codes' requirements. In particular, reactive and active power requirements of grid codes should be taken into account in more depth in the future LVRT solutions.

Contents

1. Introduction

Fast growing of worldwide wind power generation has led to regulating new grid codes. One of the most important requirements of such grid codes is low voltage ride through (LVRT) or

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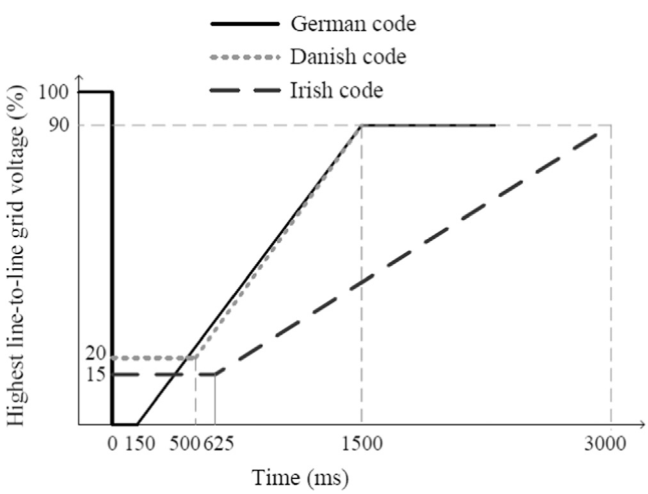

Fig. 1. Some LVRT curves.

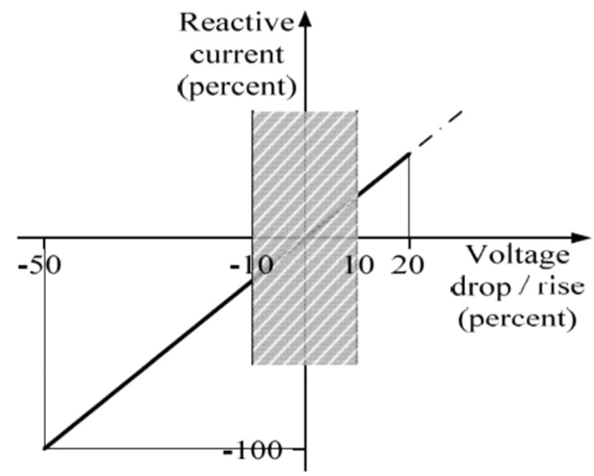

Fig. 2. Reactive current requirement of German grid code.

fault ride through (FRT) capability of wind turbines. It means that wind turbines should tolerate voltage dips at their terminals and remain connected to the grid to support voltage and frequency during and after the fault, respectively. The voltage dip may occur in result of short circuit, starting of induction machines, disconnection of capacitive loads, etc.

Wind turbines equipped with doubly fed induction generator (DFIG) is the dominant technology used in recent years. Although this generator benefits from advantages such as variable speed operation by means of fractionally rated converter but it suffers from high sensitivity to grid disturbances like as voltage dips. DFIG demonstrates problematic LVRT behavior in comparison with other types of wind turbines. In the faulty condition, its rotor may experience damaging over-currents, its DC link voltage may go beyond the allowable limit and its torque oscillation may reduce the lifetime of drive train.

In consequence, extensive study has been carried out both in analysis and improvement of DFIG wind turbine LVRT. Although some brief reviews have been done in literature about DFIG LVRT [1,2], a more detailed and comprehensive overview is required to present an updated conclusion of LVRT researches as well as the gaps should be filled in the future studies. This paper tries to do this by means of introducing DFIG LVRT problems and solutions reflected in the extensive reviewed investigations.

2. Grid codes' LVRT requirements

A review on the grid code technical requirements for wind farms is carried out in [3,4]. A brief review on LVRT requirements and DFIG LVRT solutions is also presented in [5]. LVRT requirements of grid codes could be summarized as follows:

- Wind turbines should remain connected to the grid during certain level of voltage dips at point of common coupling (PCC) for pre-determined time periods [6]. For instance, the German, Danish and Irish voltage-time curves are shown in Fig. 1. The wind turbines should remain connected to the grid during the faults in the regions above the curves. Standard IEC 61400-21 also defines voltage drop tests for wind turbines for verifying their response to grid voltage dips. Different kinds of symmetrical and asymmetrical voltage drops are specified with different voltage magnitudes and fault duration times.
- Wind turbines should produce certain amount of reactive current during the voltage dips to support grid voltage stability. Reactive current requirement of German grid code is illustrated in Fig. 2 as an example. It can be observed from this figure that the wind turbine should produce 2 percent reactive current per each percent voltage dip for the voltage dips from 10 percent up to 50 percent.
- Wind turbines should generate active power immediately after fault clearance to support grid frequency.

3. DFIG wind turbine modeling for LVRT studies

Experimental studies are reported in some works as the most precise method for analyzing the DFIG wind turbines during voltage dips. A DFIG LVRT test facility in laboratory scale is described in [7]. Accurate simulation could be sufficient depending on the required precision for a study. A 3 MW wind turbine with DFIG is completely modeled and experimentally verified by LVRT tests in [8]. DFIG modeling for LVRT analysis is also discussed in [9]. A study on the modeling of DFIG under short time unsymmetrical voltage disturbance is carried out in [10]. Finite element modeling and analytical modeling are compared to investigate the influence of modeling approach on the simulation results.

Based upon the published reports, following results about the simplifications are obtained:

Although usually 4th order model is considered for DFIG [11,12], but a simplified model is presented in [13] which demonstrate a satisfactory results for LVRT simulations. The two axis 4th order model for DFIG in the synchronously rotating reference frame can be stated as (1)–(5) [13]:

$$v_s = R_s i_s + j\omega_s \lambda_s + \frac{d\lambda_s}{dt} \tag{1}$$

$$v_r = R_r i_r + j(\omega_s - p\omega_r)\lambda_r + \frac{d\lambda_r}{dt} \tag{2}$$

$$\lambda_s = L_s i_s + M_{sr} i_r \tag{3}$$

$$\lambda_r = M_{sr} i_s + L_r i_r \tag{4}$$

where, subscripts s and r denote the stator and rotor, respectively. Voltage, current and flux linkage are represented by v, i, and λ, respectively. In addition, R and L are the resistance and self inductance, respectively, and M_{sr} denotes the mutual inductance of stator and rotor. It should be noted that ω_s is the stator electrical angular speed, but ω_r is the rotor mechanical angular speed.

- Detailed and simplified converter models are compared in [14]. It is shown that two mentioned models have a good agreement.