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Doubly-fed induction generator based wind turbines: A comprehensive review of fault ride-through strategies

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A B S T R A C T

This paper presents an over-review of various strategies applied to enhance the fault ride-through (FRT) capability of the doubly-fed induction generators (DFIGs) based wind turbines (WTs) during transient-state. As the DFIG based WT system is sensitive to any grid disturbance, various FRT techniques based on: (i) installation of additional protection circuits, (ii) installation of reactive power injecting-devices and (iii) specific control approaches/structures have been proposed in the literature. Usually, the protection circuits or control structures are applied to limit the generated rotor over-current and undesirable dc-link over-voltage during grid disturbance. Meanwhile, the reactive power injecting-devices surpass any deficiency of the reactive power so as to improve the transient performance of the DFIG based WT and automatically bound the rotor current and the dc-link voltage. Actually, many research findings demonstrate an efficient protection of the DFIG without jeopardizing its operating strategy during transient-state. Therefore, this study focuses on emphasizing the present status of the rotor over-current and dc-link over-voltage protection solutions e.g. the crowbar and its related protection circuits, the reactive power injecting-devices such as the static synchronous compensators (STATCOM) and dynamic voltage restorer (DVR). Moreover, some control (modified) approaches/structures for limiting the inrush rotor currents which are based on linear and nonlinear control strategies are presented. Following the description of the overall system characteristics under steady-state and transient-state in the *d–q* axis, various protection strategies are extensively discussed to reveal their role to improve the FRT. Then, typical case studies are presented to demonstrate and support the reviewed FRT schemes. In that case, using the simulation results from the MATLAB/Simulink software the effectiveness of each case study during network faults are analyzed and compared.

Contents

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1. Introduction

Motivated by the high dependence of the global economy on the fossil fuels and environmental concerns, the focus on the alternative sources of generating electricity is sky-rocketing rapidly. With such a trend towards the diversification of the energy market, wind power is one of the fastest growing sustainable renewable energy resources (RERs) [1–3]. Recently, several supportive regulations for operations of distributed generation unit particularly the wind turbines (WTs) have been provided by different countries which are referred to as grid-codes [4–6]. Looking into the increasing share of the wind power in power system and the updated technical requirements for grid connection and operation, variable speed generators (VSGs) have been the focal point in the WTs research industry. In addition, due to the advancement in the field of power electronics and control technology the VSGs are becoming more popular nowadays [7]. They can be controlled to meet the entitled requirements of the grid or isolated energy services as they provide reactive power and frequency support apart from the active power supply.

Among the VSGs, the doubly-fed induction generators (DFIGs) have been widely applied for wind farms (WFs) applications because of their advantages such as variable speed constant frequency operating capability and active/reactive power controllability. Basically, the stator of the DFIG is directly linked to the grid, while the rotor slip-rings are tied-up to the grid via the partially rated back-to-back converters whose capacities fall within 25% to 30% of the total system ratings [8–10]. Hence, under steady-state operating condition, a rotor-side power converter (RSPC) is normally employed to control the DFIG speed and reactive power exchange with the grid via its stator terminals while a grid-side power converter (GSPC) is adopted to regulate the dc-link voltage and the reactive power exchange with the grid. However, during transient-state conditions, the DFIG based WT is very sensitive to any grid disturbances, especially to the voltage dips. Any abrupt drop of the grid voltage such as the symmetrical or asymmetrical faults may cause the stator voltage dip and stator current oscillations, stator active/reactive power and electromagnetic torque pulsations [10]. Furthermore, the generated stator current oscillations may lead to the high inrush rotor current due to the strong coupling between the stator and rotor circuits. Such a phenomenon can considerably affect the performance of the DFIG under transient-state. So, in the previous time, that is before the renewal of the stringent grid-codes these generators were required to disconnect immediately after fault occurrence to protect the RSPC as well as the dc-link capacitor unless the converter is significantly over-rated [11–14]. Nonetheless, the increased penetration of WTs into the power system gives a reflection on large-scale disconnections that may further weaken the grid and cause a considerable impact on the stable grid operation.

Therefore, appropriate measures have been taken in order to: (i) protect the power converter switching devices against the rotor over-current, (ii) protect the dc-link capacitor against dc-link over-voltage and (iii) ensure that the wind turbine remains connected

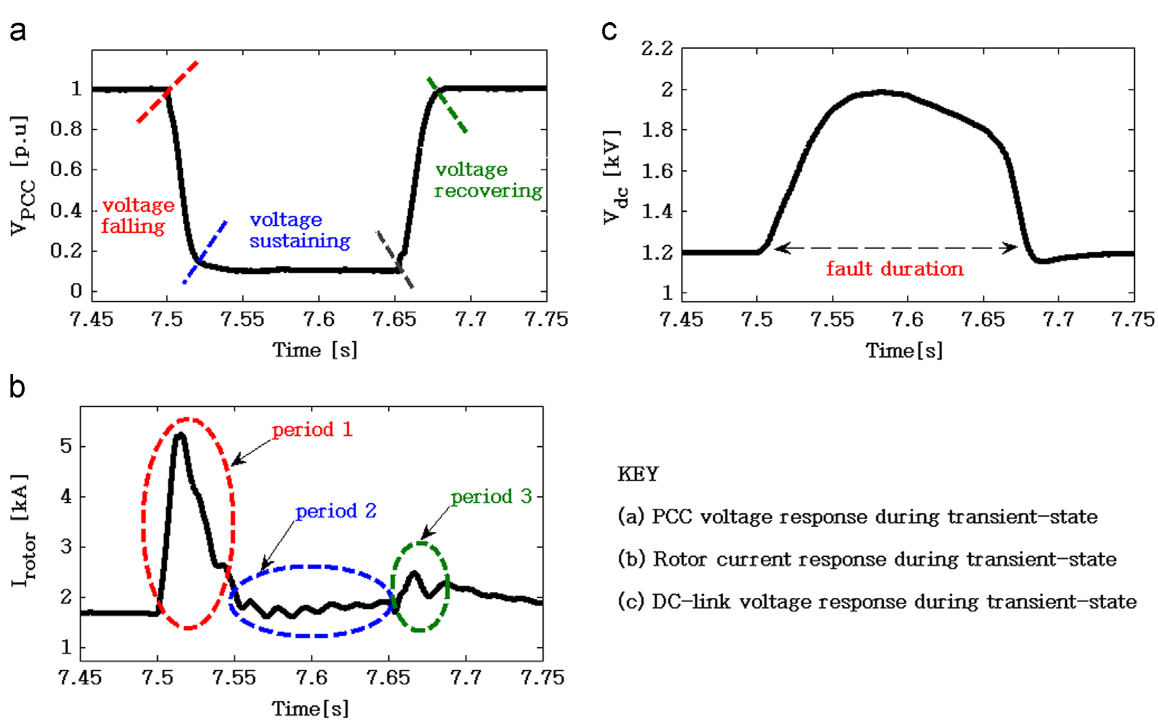

Fig. 1. Transient response of the DFIG based WT. (a) PCC voltage. (b) Rotor current. (c) DC-link voltage.