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Impact of VSC faults on dynamic performance and low voltage ride through of DFIG

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ABSTRACT

A doubly-fed induction generator's (DFIG's) sensitivity to external faults has motivated researchers to investigate the impact of various grid disturbances, such as voltage sags and short circuit faults, on its low-voltage ride-through (LVRT) capability. However, no attention has been paid to the impact of internal faults in voltage source converters (VSCs), that interface a DFIG with the grid, on the dynamic performance of the machine. This paper investigates the impacts of various VSC faults, on the dynamic performance and LVRT capability of a DFIG. Faults such as open and short circuit within VSC switches and across the DC-link capacitor are considered in this paper. The impact of internal VSC faults when they occur within the grid side converter (GSC) and rotor side converter (RSC) is investigated. Compliance of the voltage profiles of a DFIG with the LVRTs specified in the recent grid codes of the USA, Spain, Mexico, Denmark, Ireland, Germany, Quebec and the UK are examined for the faults studied. The simulation results show that these faults should be considered in designs of protection systems aimed at avoiding any catastrophic failure of the converter switches or wind turbine.

Introduction

Wind energy has become one of the most popular green renewable energy resources worldwide. The total global amount of wind generation installed during the period from 1996 to 2011 reached 238.351 GW [1] and wind energy is expected to provide ten percent of global electricity generation by the year 2020 [2]. Of the variable-speed constant-frequency wind turbines available, the doubly-fed induction generator (DFIG) has been a popular candidate for wind energy conversion systems (WECSs) due to its advantages [3–6] as, compared with fixed-speed induction generators, it has greater power capture, fewer mechanical stresses and less acoustical noise [4] and, compared with full-converter variable-speed generators, it is preferable in terms of its size, cost, reduced losses and weight of its small converter [7]. Voltage source converters (VSCs) that interface a DFIG and AC grid are rated at 30% of the generator's power capacity for a rotor speed range of ±30% [8,9] which makes a DFIG-based WECS very sensitive to grid disturbances that may lead to catastrophic failure of the wind turbine and converter switches if no adequate protection scheme is installed [10]. As the rotor-side converter (RSC) operates in a low slip-frequency range of ±30% of the line frequency, which may cause high temperatures and a reduced insulated gate bipolar transistor (IGBT) power capability [11], IGBT-based converters can easily experience failure [12] which, in the IGBT or controller circuit, can result in a rotor over-current. The common solution for protecting a converter against a DFIG rotor over-current is to connect a crowbar circuit across the rotor terminals to isolate the converter from the rotor when the rotor current exceeds the maximum safety margin, while the DC-link over-voltage is controlled by a resistive chopper that can dismiss the excess energy [13].

Statistical surveys indicate that about 38% and 53% of converter failures are due to faults in their switches and control circuits respectively [14,15]. Another study shows that about 60% of failures in VSCs are attributed to open- and short-circuit faults across the DC-link capacitor [10]. A recent industry-based survey concludes that converter switches, capacitors and gate control circuits are the components most susceptible to converter faults [16].

VSCs are subject to some common faults, such as fire-through, flashover and DC-link faults [17–21]. Although most internal converter faults self-clear, when their causes are of a transient nature [20], they can still have a detrimental impact on the overall performance of a DFIG-based WECS. Researchers have paid attention to the dynamic performances of DFIG-based WECSs during various

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grid disturbances, such as load fluctuations, voltage sags and swells, and short-circuit faults on the grid side [22–29], and some studies have investigated the effect of internal converter faults on the performances of high-voltage DC (HVDC) systems [30–32]. However, no attention has been given to the impacts of such faults on the overall performance of a DFIG-based WECS and its compliance with recently developed grid codes.

This paper investigates the impacts of various faults in the GSC and RSC of a DFIG-based WECS on the dynamic performance of the DFIG and simulates open- and short-circuit faults across the DC-link as common converter faults. Compliance of the DFIG's performances under such faults with the recent low-voltage ride-through (LVRT) grid codes of the USA, Spain, Mexico, Denmark, Ireland, Germany, Quebec and the UK are also investigated.

System description and controller

The single-machine infinite-bus (SMIB) system shown in Fig. 1 qualitatively exhibits important characteristics of the behavior of a multi-machine system; it is useful for describing the general concepts of power system stability and is relatively simple to study [33–35], it is simulated using the EMTDC/PSCAD software to perform the investigations proposed in this paper. As shown in Fig. 1, the DFIG stator terminals are connected to the grid through a coupling transformer and a short transmission line, the rotor windings are fed through back-to-back IGBT-based VSCs with a common DC-link capacitor and chopper to limit the capacitor's over-voltage while the GSC and RSC of the DFIG are controlled by a vector control based on those in [36,37].

GSC pulse width modulation (PWM) vector control

The main task for the GSC is to control the power exchange between the AC grid and DC-link to maintain the DC voltage across the capacitor within permissible levels. By neglecting the switching harmonics and converter loss, the active and reactive power flows, P_g and Q_g respectively, between the GSC and AC grid can be calculated by [37]

$$P_g = v_{dc} i_{dcg} = \frac{3}{2} v_{dg} i_{dg} \tag{1}$$

$$Q_g = -\frac{3}{2} v_{dg} i_{qg} \tag{2}$$

where v_{dg} and v_{qg} are the grid voltages in the d–q reference frame, and i_{dg} and i_{qg} the GSC d-and q-axis currents. As, in steady-state operation, the grid voltage is constant and hence v_{dg} will be constant and, as a result, the active and reactive power P_g and Q_g, will be controlled via controlling i_{dg} and i_{qg} respectively, as seen in Fig. 2.

According to [37], the relation between the DC and grid-side voltages can be calculated by

$$v_{dg} = \frac{m}{2\sqrt{2}} v_{dc} \tag{3}$$

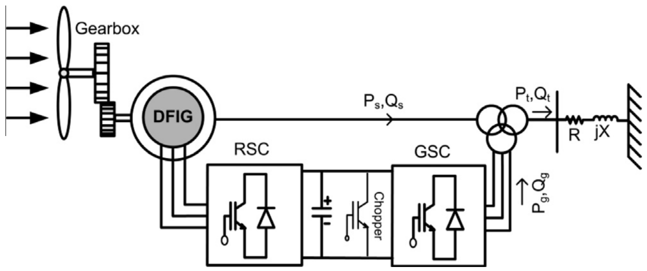

Fig. 1. Typical configuration of DFIG connected to grid.

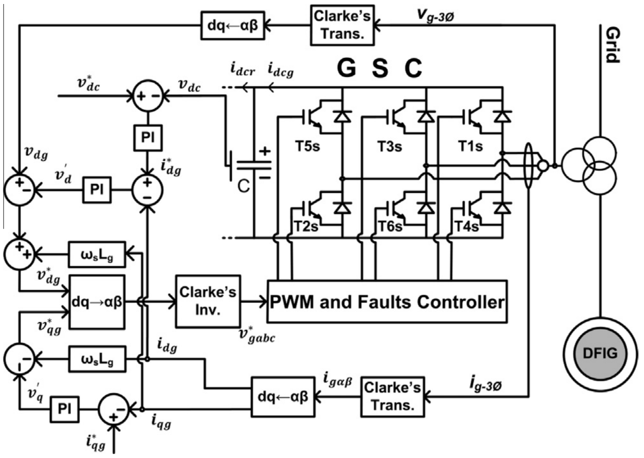

Fig. 2. Grid-side vector control system.

where m is the PWM index of the GSC. The DC voltage as a function of the capacitor current can be given by

$$c\frac{dv_{dc}}{dt} = i_{dcg} - i_{dcr} \tag{4}$$

where i_{dcg} and i_{dcr} are the capacitor currents in the GSC and RSC respectively.

From Eqs. (1), (3) and (4), the DC voltage dynamic is described in terms of i_{dg} as

$$c\frac{dv_{dc}}{dt} = \frac{3}{4\sqrt{2}} m i_{dg} - i_{dcr} \tag{5}$$

The grid-side voltage in the synchronous rotating frame can be calculated by:

$$v_{dg} = R_g i_{dg} + L_g \frac{di_{dg}}{dt} - \omega_s L_g i_{qg} + v_{gcd} \tag{6}$$

$$v_{qg} = R_g i_{qg} + L_g \frac{di_{qg}}{dt} - \omega_s L_d i_{qg} + v_{gcq} \tag{7}$$

where v_{gcd} and v_{gcq} are the GSC voltages in the d–q reference frame, ω_s the synchronous angular speed, and R_g and L_g the filter resistance and inductance respectively.

The Clarke–Park transformation [4] is used to convert the stator terminal currents from the d–q reference frame to the α–β reference frame, as shown in Fig. 2 and given by

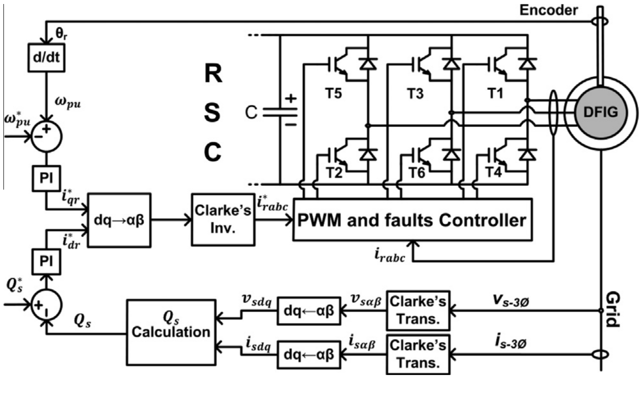

Fig. 3. Rotor-side vector control system.