

Fault ride-through capability of a DFIG in isolated grids employing DVR and supercapacitor energy storage



Spyros I. Gkavanoudis, Charis S. Demoulias*

Department of Electrical and Computer Engineering, Aristotle University, Thessaloniki 54124, Greece

ARTICLE INFO

Article history:

Received 9 January 2014

Received in revised form 18 December 2014

Accepted 24 December 2014

Available online 17 January 2015

Keywords:

Doubly-Fed Induction Generator

Fault ride-through

Dynamic Voltage Restorer

Stand-alone operation

Synchronous generator

Power quality

ABSTRACT

In order to utilize Doubly Fed Induction Generators (DFIGs) as primary power source in an isolated system, they should be able to regulate the voltage and frequency of the system as well as ride-through faults. This paper proposes a new control strategy for a DFIG operating in an isolated power system, accomplished by a Dynamic Voltage Restorer (DVR) and a Supercapacitor Energy Storage System (SCSS), in order to ride through symmetrical and asymmetrical faults. During faults, the DFIG continues to operate normally, while the active power mismatch is handled by the SCSS. In particular, during asymmetrical faults, the DFIG and the DVR are properly controlled in order to feed the non-faulty phases uninterruptedly. When integrated in a power system with conventional synchronous generators, the proposed control strategy improves the Fault Ride-Through (FRT) capability of a DFIG, while providing frequency and voltage support to the system throughout the fault duration. Thus, the transient stability of the power system is significantly improved. The effectiveness of the proposed control method under different fault conditions is verified by detailed simulation results.

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Introduction

Wind turbine generators (WTGs), as one of the most important renewable energy sources, are very often used to power islanded networks and/or individual loads. Among the various WTG types, the DFIGs are widely used due to their variable speed operation, the partially rated back-to-back power converter system and their relatively simple control [1]. However, a major challenge for the DFIGs is the operation during voltage sags and short circuits. When a short circuit occurs on the grid side, the rotor currents rise and if the converter is not protected against these high currents, it will be damaged [2,3].

Several Fault Ride-Through and power quality solutions (e.g., power smoothing), for DFIGs operating in large utility grids, have been proposed in the literature [4–6]. Concerning the operation of DFIGs in isolated grids, various control methods have been proposed that deal with the steady state or dynamic conditions. In [7], an Indirect Stator Flux Oriented (ISFO) control method for a stand-alone DFIG is presented. The DFIG is controlled to generate the system voltage and frequency and maintain it within the permissible operational limits, irrespective from the shaft speed. A DFIG operating in dual mode, grid-connected and islanded and its ability to

improve the dynamic stability of the system has been presented in [8–10]. In [11] and [12], control strategies for an isolated DFIG operating under unbalanced voltage conditions and feeding non-linear loads are proposed.

However, in isolated power systems supplied by WTGs, it is of vital importance for the generators to be capable of riding-through voltage disturbances, as they might be the primary power source. Only in [13], a FRT method for a DFIG operating in a microgrid was investigated in case of three-phase symmetrical faults of very short duration. It was shown that the DFIG can survive the faults by storing the energy surplus in its inertia.

In this paper, the integration of a DVR in a DFIG, operating within isolated grids, to allow uninterruptible fault ride-through of symmetrical and asymmetrical faults is proposed. Two cases are examined: (a) a stand-alone DFIG is the only power source supplying local loads and (b) the DFIG operates in cooperation with a conventional synchronous generator (SG), sharing the load demand according to a droop control strategy. In both cases the DVR can compensate the voltage disturbances in the faulty line(s), allowing the DFIG to remain fully operational while being protected against the high fault currents. The control strategy integrates dual control mode; under normal operation the ISFO method is employed to control the voltage and frequency of the isolated system. During faults- and the activation of the DVR- the control mode changes to Direct Stator Flux Oriented (DSFO), in order to directly control the generated active and reactive power.

* Corresponding author. Tel.: +30 2310995960.

E-mail addresses: gavanoudis@gmail.com (S.I. Gkavanoudis), chdimoul@auth.gr (C.S. Demoulias).

A SCESS sharing the same DC-link with the Rotor Side Converter (RSC) and the Line Side Converter (LSC) is employed to absorb or release active power during faults.

Additionally, under asymmetrical faults, the DFIG and the DVR are properly controlled to provide high quality voltages to the “healthy” phases. This necessity stems from the fact that during asymmetrical faults additional currents are induced in the rotor of both the DFIG and the SG. These currents are sensed by the stator as additional excitation, causing the voltages of the “healthy” phases to increase [14,15]. In this paper, the voltage quality is improved by controlling the active and reactive power supplied both through the stator of the DFIG and through the LSC. Aim of the control is to maintain the load voltages at the “healthy” phases, close to their pre-fault level. The developed control strategies differ according to the examined grid topology (stand-alone or parallel operation), as described in detail in Section ‘Control strategy under symmetrical and asymmetrical faults’.

In the case of parallel operation of a DFIG and a conventional SG, the proposed FRT control strategy is tested under single-phase-to-ground faults and phase-to-phase faults. In both situations the grid voltages become heavily unbalanced and a severe third harmonic voltage component is present [15,16]. The DVR compensates for the distorted voltages so that the DFIG keeps on operating normally. Moreover, the LSC is controlled to provide voltage and frequency support to the isolated grid. Finally, the LSC integrates an active current filter operation to compensate the third harmonic voltage component and supply the loads connected to the “healthy” phases with high quality voltages.

In summary, the innovative parts of this paper are: (a) improve the FRT capability of a stand-alone DFIG under symmetrical and asymmetrical faults, (b) in case of asymmetrical faults, uninterruptedly supply the “healthy” phases with high quality voltages, (c) ride-through faults when operating in parallel with a conventional SG, (d) in the latter case, support the voltage and frequency of the power system during the faults, through the control of the LSC and (e) improve the voltage quality of the “healthy” phases, by compensating the severe third harmonic component, that is present (when operating in cooperation with a SG) in case of asymmetrical faults.

The paper is organized as follows. In Section ‘Topology of the isolated grid’, the examined system topology is presented. The power and control models during steady state and fault conditions, are respectively described in detail in Sections ‘Steady-state operation’ and ‘Control strategy under symmetrical and asymmetrical

faults’. Finally simulation results demonstrated in Section ‘Simulation results’ verify the effectiveness of the proposed control strategy.

Topology of the isolated grid

A single line layout of the power system topology, examined in this study, is presented in Fig. 1. In the general case, a DFIG and a conventional synchronous generator (SG) feed the local loads. A particular case is formed when the SG is absent and the loads are fed only by the DFIG. The wind turbine is coupled to the shaft of a DFIG through a gear box. The stator of the machine is connected to the AC bus through an interface transformer, whereas the rotor is connected to the transformer through a back-to-back power converter system (PCS) and a three-phase LC filter. The PCS consists of the Rotor Side Converter (RSC) and the Line Side Converter (LSC), which are connected to each other through a DC-link capacitor. To protect the generator from faults and voltage disturbances, a DVR is placed at the stator terminals of the DFIG. In steady state operation, the DVR is disabled and is activated only during voltage sags. The DVR shares the same DC-link with the RSC, the LSC and the high-voltage side of the SCESS. The SCESS used in this study, is formed by a DC/DC half bridge converter and a supercapacitor bank.

Steady-state operation

During steady state operation, the DFIG is controlled – through the RSC – under an Indirect Stator flux Oriented (ISFO) method (denoted as state “1” in Fig. 2) and it supplies a reference voltage and frequency for any shaft speed [7]. Combined with a droop control strategy, the ISFO-controlled DFIGs are easily integrated within isolated grids, both in stand-alone operation as well as in cooperation with other power sources [17]. The reference voltage magnitude is set according to a variable Q - V droop curve, while the frequency command is set through variable P - f droop curve. The coefficients of the variable droop curves of the DFIG are adjusted according to the available wind power [13]. The voltage and frequency of the system is determined by the combination of the droop characteristics of the DFIG and the SG (when present) and the active and reactive power demand of the loads.

The control objective of the RSC is to regulate the rotor excitation currents. A synchronously rotating dq frame is aligned so that $\lambda_{qs} = 0$. In order to maintain the field orientation, the reference

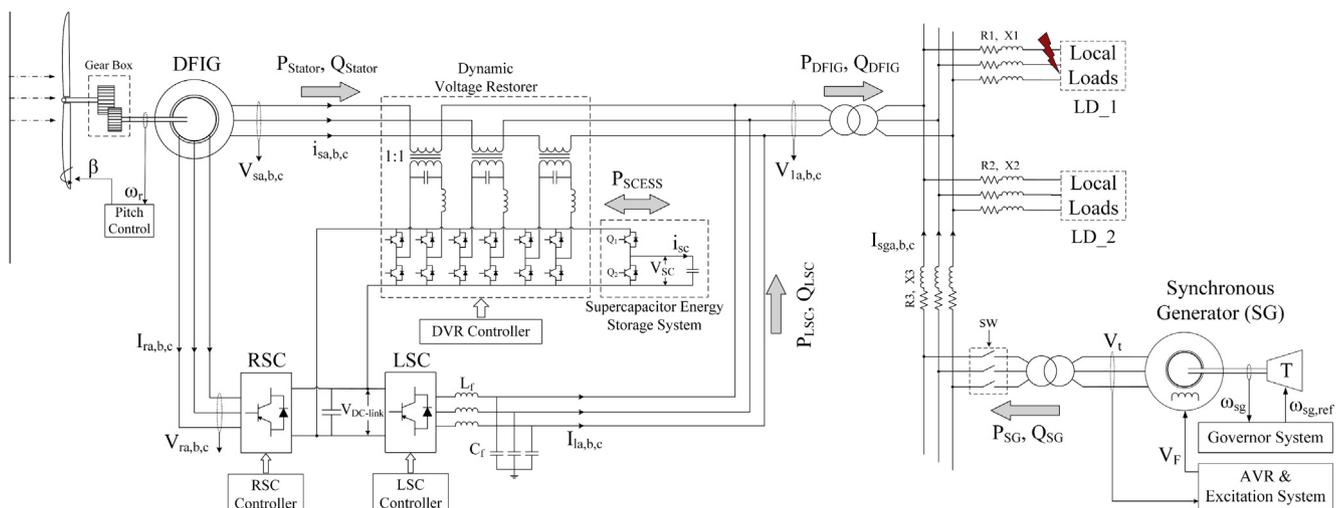


Fig. 1. System topology.

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