BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 62 (66), Numărul 4, 2016
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

GRID FAULT OUTCOME ON ASSESSING DOUBLY-FED INDUCTION GENERATOR WIND TURBINE VOLTAGE RECOVERY OUTPUT

BY

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Received: November 25, 2016
Accepted for publication: December 20, 2016

Abstract. The present paper studies the DFIG (Doubly-Fed Induction Generator) variable speed wind turbines voltage recovery capability after external short-circuit fault removal. After external short-circuit fault, the transient stability of wind power system relies upon fault conditions and network parameters. If fault conditions are severe, the protection devices in the rotor circuit will be triggered which involves that the generator rotor is short-circuited and the rotor side converter is deactivated. In this situation, to recover the voltage at the wind turbine terminal and restore the wind turbine normal operation, after the fault removal, effective measures should be performed. Simulations are performed using the Matlab&Simulink environment.

Key words: doubly-fed induction generator; phase fault; power system stability; protection device; Simulink model.

1. Introduction

Environmental issues related on climate change and the increase of energy consumption, determined the international community to give serious

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significance to the energy generation from renewable sources like wind, hydro, solar or geothermal.

Integrating large quantities of renewable energy into the power system cannot be realized without system disturbance; consequently, it is very important to assess system stability. For this reason each country grid codes or requirements are constantly revised.

Nowadays, the most common type of wind turbine is based on Doubly-Fed Induction Generator (DFIG), which has the advantage that it can operate both at sub-synchronous and super-synchronous speeds, making it appropriate for wide range of wind speed (Sun *et al*., 2014).

This kind of generator is used on the grid connected wind energy conversion system to satisfy grid requirements such as grid stability, fault-ride through (FRT), power control and voltage recovery (A. D. Hansen *et al*., 2007).

The present study focuses on voltage recovery of variable speed wind turbines with Doubly Fed Induction Generator, presented in Fig.1, after grid disturbance removal. In power systems are possible different types of grid faults, such as: phase to ground, phase to phase to ground and three phase short circuit. When a fault occurs, it must be isolated by the appropriate breakers or protection relays.

This type of wind turbine allows variable speed operation. To offset the difference between the mechanical angular frequency and grid frequency are used AC/DC/AC converters. The Doubly-Fed Induction Generator is provided with back-to-back converters, a rotor-side converter (RSC) and a grid-side converter (GSC), controlled independently (R. Beniugă *et al.*, 2012).

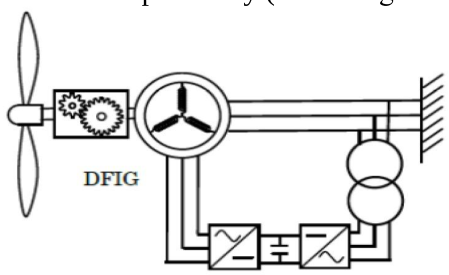

Fig. 1 – DFIG wind turbine model.

The main idea in a Doubly-Fed Induction Generator is that the rotor-side converter controls the active and reactive power by controlling the rotor current components, while the grid-side converter controls the dc-link voltage and ensures the operation at unity power factor (Mandal, 2014).

2. DFIG Wind Turbine Model and Control System

In order to simulate a wind turbine, different models must be designed such as: the wind speed model, the transmission system aerodynamic model, the Doubly-Fed Induction Generator model, the converters model (illustrated in Fig. 2), the transformer and control system model.

The automatic control system model permits controlling, on one side, the voltage by using the power converters, and on other side, the pitch angle.

The aerodynamic model allows to outstand the wind speed and pitch angle effects on the mechanical power generated during and after a grid fault. The wind turbine aerodynamic model is driven by the turbine's power characteristic. Small variations of pitch angle may lead to major effects on generated power. In order to limit the pitch angle, the control model uses a proportional – integrator (PI) controller, which uses a servomotor model, ensuring thus a certain degree of variation and a specified speed (Justo *et al.*, 2015). The RSC converter is able to adjust the turbine generated power, as well as the voltage or the reactive power in the point of common coupling.

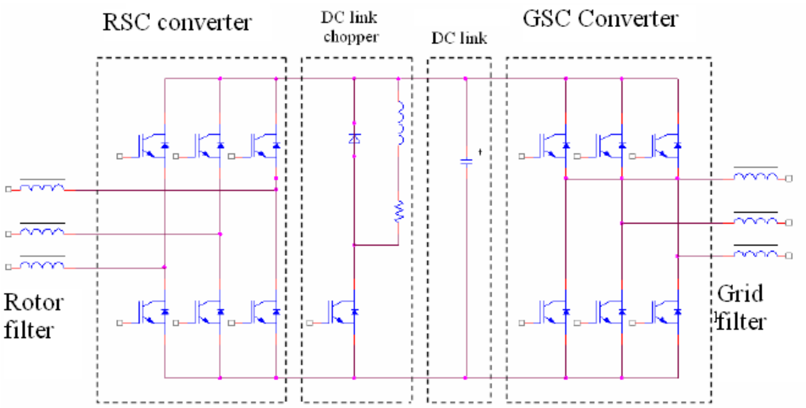

Fig. 2 – DFIG wind turbine power converter.

The GSC converter aims to maintain constant the dc-link voltage and to adjust the reactive power flow to the grid. The dc-link voltage and the reactive power are compared with their reference signals, and the obtained errors are passed through a PI controller to generate reference signals of currents components (Justo *et al.*, 2017). In Fig. 3 is presented the Simulink model of a GSC converter control diagram.

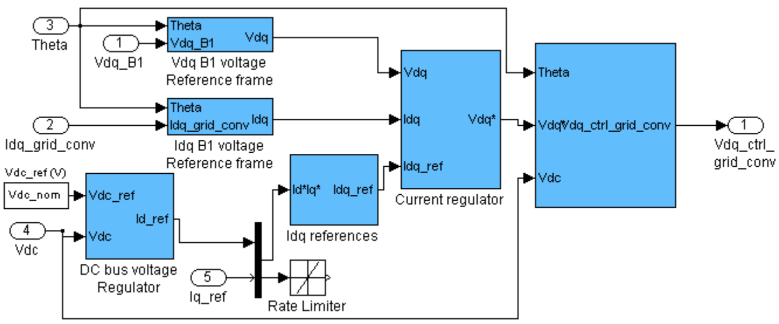

Fig. 3 – Simulink GSC converter control diagram.

The drive train system converts the power captured by the wind turbine into mechanical power and then, using the DFIG, in electrical energy, which is transmitted to the grid by means of the stator and the rotor windings. The control system elaborates the pitch angle and voltage command signals, in order to control the wind turbine power, the dc-link voltage and the grid terminal voltages (Satish, 2011).

3. Voltage Recovery for Grid Faults in the Simulated System

The aim of the paper is to study the voltage recovery capability of a DFIG wind turbine, when are simulated different types of external grid faults, at 10 km distance from the wind farm, in the distribution grid, at the moment t = 5 s. It is highlighted the time frame between fault occurrence and the fault removal, by the mean of protective devices, with focus on voltage recovery.

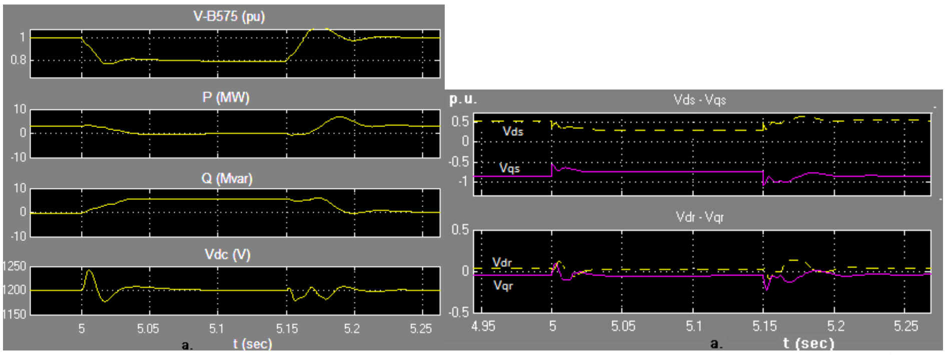

Fig. 4 – DC-link voltage, Active and Reactive power, Stator and Rotor voltage, for single-phase-to-ground grid fault.

For this scenario, it was taken into consideration a wind farm with 9 MW installed power connected to a 25 kV power grid.

In Fig. 4 are presented the graphical representations of DFIG wind turbine behaviour, for a single-phase-to-ground grid fault scenario. It can be observed that, until the moment t = 5 s, the wind power systems operates normally. At the time of grid fault occurrence, the voltage (V-B575), at the wind turbine terminals falls to 0.8 p.u., in this situation, it is needed a reactive power (Q) supply, as it can be observed in the diagram. In the same time, the active power (P) production slightly declines. For the dc-link voltage (Vdc), it can be noticed a small rise, with less than 4% of rated value, until 1,244 V. In this case, the protection devices of the DFIG generator converters are not activated, since there aren't recorded over-voltages (Vds, Vdr). The voltage recovers, when the fault is removed, at the moment t = 5.15 s.

For a two-phase-to-ground fault in the same grid, simulation graphs are illustrated in Fig. 5. The fault is produced in the same moment as it is described in the first scenario. During the fault, the active power P also goes down, while the reactive power Q shows a slowly increase. In this situation, the dc-link voltage climbs with more than 8% of rated value, so the protection devices are triggered. The wind turbine generator rotor is short-circuited and the RSC is deactivated while the GSC stays connected to the grid, in order to adjust the dc-link voltage (Vds, Vdr).

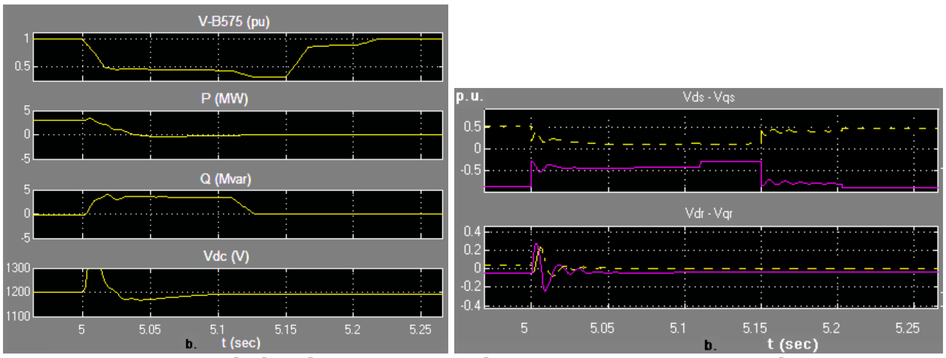

Fig. 5 – DC-link voltage, Active and Reactive power, Stator and Rotor voltage, for two-phase-to-ground grid fault.

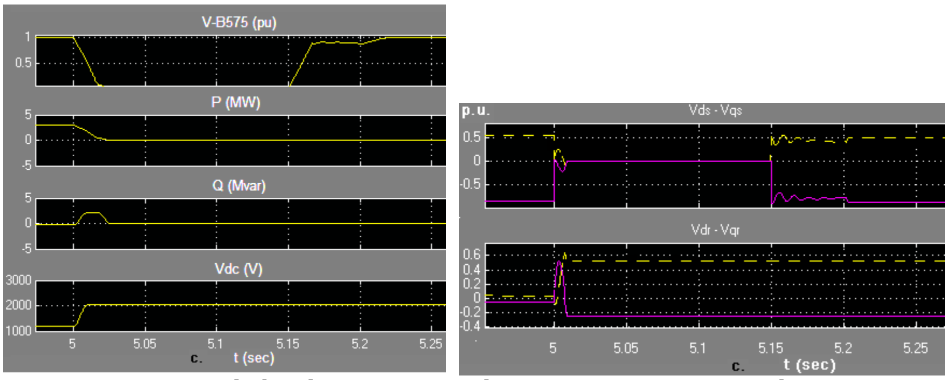

Fig. 6 – DC-link voltage, Active and Reactive power, Stator and Rotor voltage, for three phase grid fault.

When is performed a three phase grid fault simulation for the wind power system, the main results for the DFIG generator behaviour, from fault occurrence until fault removal, are highlighted in Fig. 6.

In this case, the voltage (V-B575) at the wind turbine terminals considerably decreases. The DC-link (Vdc) increases substantially and the generator rotor is disconnected, through the protection devices, avoiding thus its damage due to high currents.

4. Conclusions

This paper presents a study of a DFIG wind turbine behaviour in order to assess the voltage recovery capability after clearing a grid fault. Simulations in Matlab&Simulink were performed for three scenarios of grid fault. It was concluded that in the event of an external three phase grid disturbance, the wind turbine dc-link voltage reaches the highest value, from all the three considered scenarios and protective circuit of generator's converters must be configured appropriately, so it short-circuits the rotor from the grid, avoiding thus damages in wind turbine power electronics. It was also observed that the voltage recovery capability is faster if the fault occurs only in one phase and is slower when the fault affects all the three phases.

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IMPACTUL DEFECTELOR ÎN REȚEA ASUPRA CAPABILITĂȚII DE RESTABILIRE A TENSIUNII TURBINELOR EOLIENE CU GENERATOR CU INDUCȚIE ŞI CU DUBLĂ ALIMENTARE (DFIG)

(Rezumat)

Lucrarea de față studiază capacitatea turbinelor eoliele cu viteză variabilă prevăzute cu generator de tip DFIG de a restabili nivelul tensiunii după trecerea printr-un scurtcircuit extern. După un scurtcircuit extern, stabilitatea tranzitorie a sistemului eolian depinde de condițiile defectului şi de parametrii rețelei. În situația în care condițiile defectului sunt serioase, dispozitivul de protecție din circuitul rotoric va fi declanşat, ceea ce implică scurtcircuitarea rotorului generatorului şi dezactivarea convertorului de pe partea rotorului. În această situație, sunt necesare determinări efective, pentru restabilirea tensiunii la terminalul turbinii eoliene şi pentru restabilirea funcționării normale a turbinei eoliene, după trecerea defectului. Simulările sunt realizate utilizând mediul de lucru Matlab & Simulink.