FAULT RESPONSE FOR GRID CONNECTED OWPP WITH DFIG. ANALYTICAL APPROACH

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In this paper, the operation of an Offshore Wind Power Plant (OWPP) equipped with Doubly Fed Induction Generators (DFIGs) during faults in upstream grid and internal grid are investigated. The case study refers to a 90 MW OWPP with 20 turbines connected to the 110 kV transmission system. The modeling of OWPP is realized in Matlab/Simulink. A voltage control system was applied to each DFIG of OWPP. Single phase faults in 110 kV system and 34.5 kV grid for different distances to OWPP were investigated.

Keywords: offshore wind power plants, doubly-fed induction generators, fault

1. Introduction

The utilization of wind energy is increasing even if the space available on land is limited by space restrictions or by ecological considerations. It is expected that offshore wind power plants (OWPPs) will have an increasing importance and position in near future due to wider spaces with strong winds, less turbulence and more predictability.

More and more wind turbines are equipped with Doubly Fed Induction Generators (DFIGs) due to the many advantages DFIG offer over other type of generators. The mechanical power provided by the prime mover driving the DFIG is importantly varying (e.g., wind blowing at variable speed on the bladed rotor of a wind turbine). The DFIG allows electrical power generation at lower wind speeds, and only 30% of the power passes through the converter. Compared with a full-size one it is smaller and cheaper [1], [2].

In the last years, OWPPs are designed as large or very large projects. At transmission level a disturbance may affect the stability of the system as the OWPPs turn off. These can generate additional disturbances as result of unbalance between electrical energy generation and demand in the grid. The distribution equipment may decrease the supply continuity after a fault occurrence. The main problem of faults in the transmission grid is the short-time drop of voltage. This can determine damages to power electronics equipment and motors. That may be

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caused by uncontrolled increasing of rotor current over rated value or large voltages induced on the rotor side [3], [4].

The Doubly Fed Induction Generator model is described briefly. Then, the behavior of an OWPP with DFIGs in case of short duration fault occurring in the internal network is analyzed. A comparison is made between a fault occurring in 110 kV power system and a fault occurring in the 34.5 kV internal network. The results offer information about the expected fatigue on the generator and the converter side.

2. Doubly Fed Induction Generator

The voltage equations of the stator and rotor circuits of the induction generator can be expressed in a synchronous *d-q* reference frame [5]:

$$v_{ds} = R_s i_{ds} - \omega_s \psi_{qs} + \frac{d\psi_{ds}}{dt} \tag{1}$$

$$v_{qs} = R_s i_{qs} - \omega_s \psi_{ds} + \frac{d\psi_{qs}}{dt} \tag{2}$$

$$v_{dr} = R_r i_{dr} - (\omega_s - \omega_r)\psi_{qr} + \frac{d\psi_{dr}}{dt} \tag{3}$$

$$v_{qr} = R_r i_{qr} + (\omega_s - \omega_r)\psi_{dr} + \frac{d\psi_{qr}}{dt} \tag{4}$$

$$\psi_{ds} = L_s i_{ds} + L_m i_{dr} \tag{5}$$

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \tag{6}$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{7}$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{qs} \tag{8}$$

where: v – voltage [V], i – current [A], R - resistance [Ω], L – inductance, L_m – couple inductance [H], ψ – stator flux linkages [V·s], ω – angular speed [rad]. Indices d and q represents direct, respectively the quadrature axis components, while s and r indicate stator, respectively rotor quantities.

Figure 1 illustrates the scheme of a DFIG wind turbine connected to the grid. For the conducted analysis, was implemented a model in Matlab/Simulink.

DFIG consists of a wound rotor induction generator with back-to-back voltage source converters connecting the rotor to the grid. Converters C_{rotor} and C_{grid} are connected to the grid through a line filter to reduce the harmonics.

In figure 2 the scheme of the DFIG control system is illustrated [5].

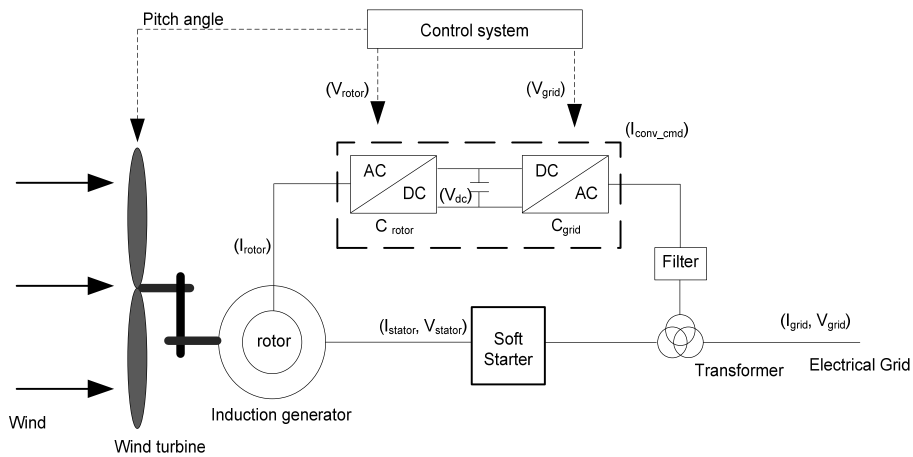

Fig. 1. The Wind Turbine and the Doubly Fed Induction Generator System.

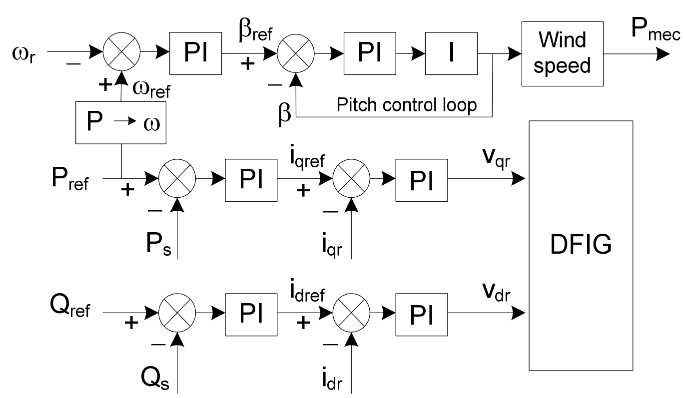

Fig. 2. Layout of DFIG control system [5].

The whole system can operate on all 4-quadrants. In figure 3 are summarized the conventional power flow directions [6]. This is definitely an advantage as the generator can either generate or absorb reactive power from/to the grid, so the DFIG can provide active power to the grid and it can also support it during system failures, short circuits with an amount of reactive power [7].

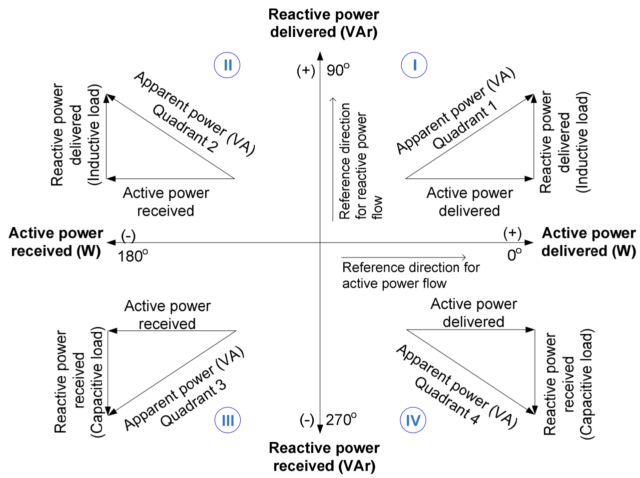

Fig. 2. Four quadrant power flow directions [6].

The DFIG control system has three parts:

- the control system of the rotor side converter C_{rotor} – used to control the wind turbine output power and the reactive power measured at the grid terminals;
- the control system of the grid side converter C_{grid} – used to regulate the voltage of the DC link and allows converter to generate or absorb reactive power;
- the control system of pitch angle – used to regulate the rotor speed by controlling the electrical power reference provided to the converter.

The generator is protected in case of short circuits with a circuit breaker, which is sized 2-3 times bigger than generator rated current. The block transformer - generator is usually protected with fuses sized 2-3 times its rated current. In case of the collector feeder, the protection is simplified by considering it as a radial distribution feeder using overcurrent relays [8].

3. Case study – 90 MW OWPP equipped with DFIGs

The case study investigates a 90 MW OWPP (20×4.5 MW) equipped with DFIGs. The OWPP has five 18 MW clusters with radial connection, as shown in figure 4. The 0.69 kV voltage level at generator terminals is increased to 34.5 kV through a 5 MVA transformer.

The induction machine and wind turbine parameters are reported in table 1.

The single-phase layout of the OWPP connected to the grid is illustrated in figure 5.

All 5 clusters are connected to a 40 MVA power transformer, placed on the offshore substation platform, which is increasing the voltage to 110 kV. The power produced by OWPP is transported to the grid through a 110 kV submarine cable.

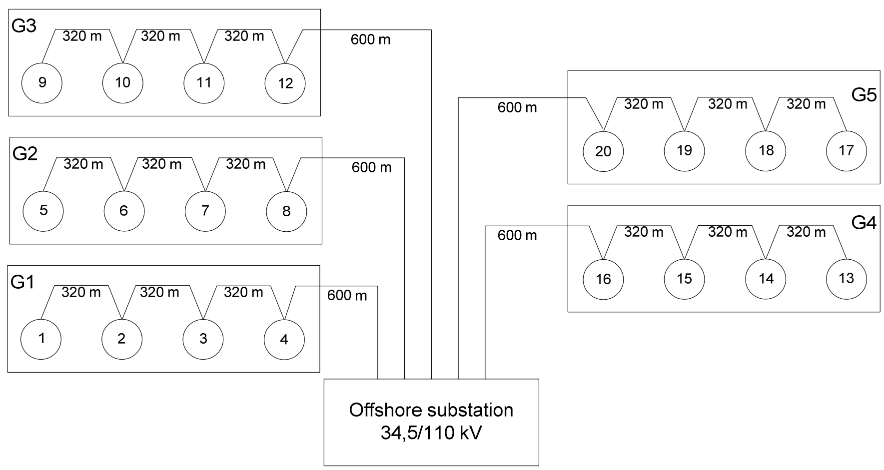

Fig. 4. Radial collector network of 90 MW OWPP.

The DFIG response to a fault occurrence, as shown in figure 5, was investigated.

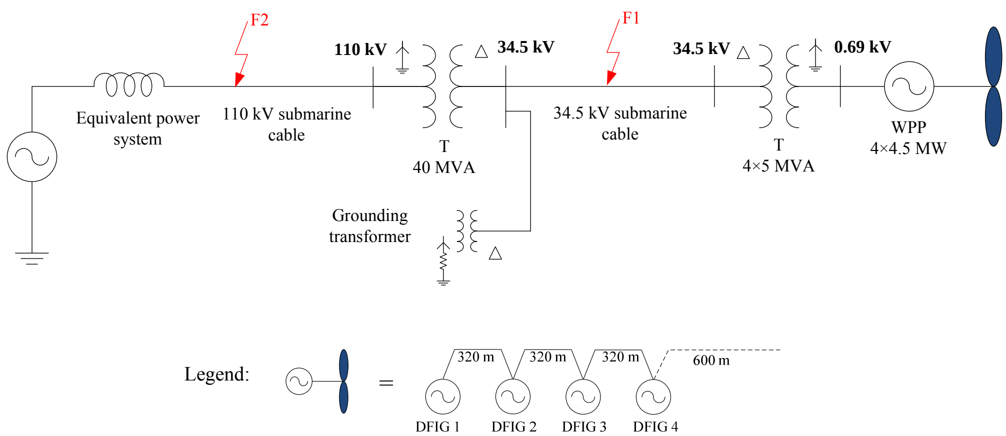

Fig. 5. Single-phase diagram of the OWPP connected to the grid.

Table 1

Induction machine and turbine parameters

Generator	
Rated power	4500 kW
Voltage	690 Vac
Rotor speed	448 rpm

Converter	
Rated power	4500 kW
Maximum power	4750 kW
Grid Voltage	690 Vac
Frequency	50 Hz

Transformer (immersed in silicone)	
Rated power	5 MVA
Voltage	34.5 kV

In the voltage regulation mode, at time instant t = 5 s, in the 34.5 kV electrical network a 9 cycle (0.18 s) phase-to-ground fault occurs. The simulation results are presented in figure 6.

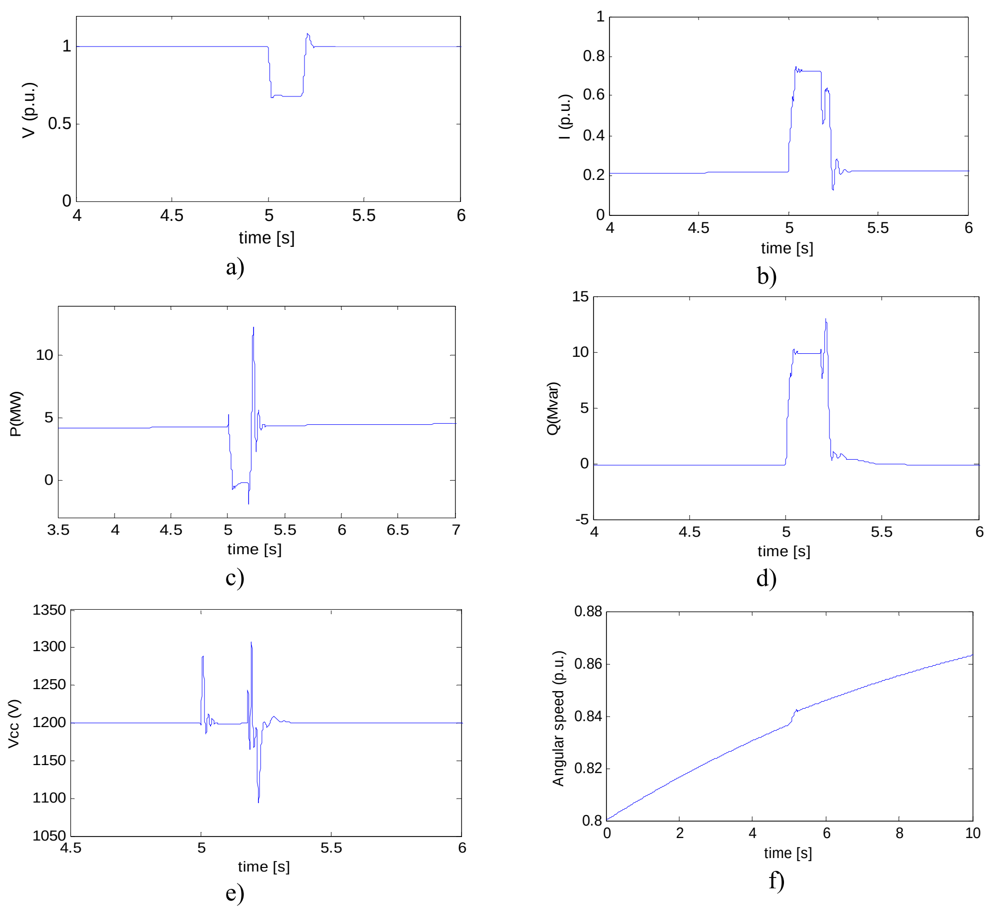

Fig. 6. DFIG response in voltage control mode to a fault occurrence:
a) the voltage at DFIG terminals; b) the electrical current at DFIG terminals; c) the power produced by cluster G_1; d) the reactive power of wind generator; e) dc voltage of DFIG; f) the angular speed.

As illustrated in figure 6, when fault occurs, the voltage drops under 0.7 p.u. The active power produced by the wind turbine during the fault is zero, and the reactive power produced by DFIG is Q =+10MVAr in order to maintain the voltage at the reference value. As illustrated in figure 6e), the fault leads to significantly increased fluctuations of the dc-link voltage.

The voltage magnitude at DFIG terminals during a fault occurring in the 34.5 kV collector system and a fault in the 110 kV power system was investigated.

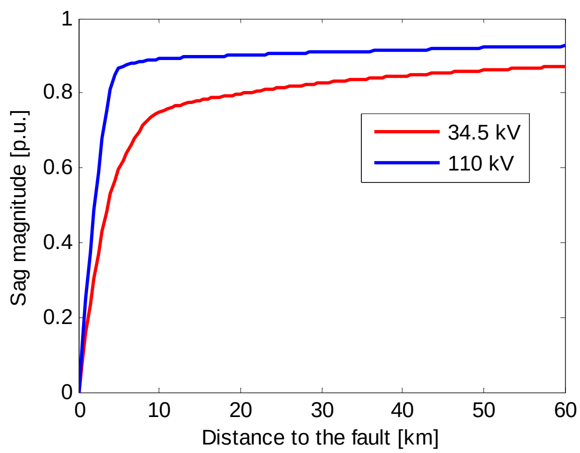

Fig. 7. Variation of voltage magnitude at DFIG terminals with the distance to the fault, for 110 kV and 34.5 kV systems.

Different distances between the fault occurrence and the OWPP were analysed. Figure 7 shows the obtained results. As it can be observed, sags due to a 34.5 kV fault are more severe than sags due to 110 kV faults.

4. Conclusions

More and larger WPPs are being located offshore and DFIG generators represent the most common generator type. It is important to know the response of DFIG to faults in order to benefit of their advantages (smaller and cheaper compared with a full-size generators, allows electrical power generation at lower wind speeds, only 30% of the power passes through the converter and the power losses are reduced).

From simulation results, it was observed that a fault occurring in the 34.5 kV is more severe than a fault in the 110 kV grid system. The maximum rotor current due to a voltage sag increases with the magnitude of the sag.

A fault occurring in the upstream network or in the internal network of a WPP may affect the normal operation of power electronic devices and other related equipment.

Acknowledgement

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