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Influence of the Reactive Power Management for Wind Power Plants in the Dynamic Voltage Stability

***Abstract**. Nowadays, the large penetration of wind power generation poses new challenges for the dynamic voltage stability analysis of an electric power system. In this paper is studied the influence of the reactive power management for wind power plants in the dynamic voltage stability of an electric power network under a fault condition, considering two different Doubly-Fed Induction Generators (DFIG) models. The simulation results were obtained using the EUROSTAG software package.*

***Streszczenie.** W artykule przedstawiono wpływ zarządzania mocą bierną w elektrowniach wiatrowych na stabilność dynamiczną napięcia w sieci elektrycznej. Zbadano przypadek dwóch różnych modeli generator. (**Wpływ zarządzania mocą bierną na dynamiczną stabilność napięcia w elektrowniach wiatrowych**)*

Keywords: Dynamic voltage stability, grid codes, reactive power management, wind power plants.
Słowa kluczowe: stabilność napięciowa, elektrownie wiatrowe..

Introduction

In recent years, with the increased presence of wind power generation in the electric power networks, many countries have established or are creating a set of specific requirements (grid codes). These grid codes are important for operation of the system and grid connection of wind power plants [1]. Contrary to previous rules, disconnection of wind power generators, in case of voltage dips, cannot be any longer accepted, since voltage and transient stability support during and after each disturbance are required [2].

The grid codes concerning wind power generation are specific of each country and cover significant technical regulatory issues. The aim of these grid codes is to ensure that the continued expansion of wind power generation does not compromise the power quality, as well as the security and reliability of the electric power network. Therefore, the risk of losing a large portion of wind power generation during fault events decreases and the Transmission System Operators (TSOs) can maintain an efficient, reliable and secure system operation even with high wind power penetration levels [3].

Currently, the wind power plants are required to be able to satisfy the voltage control strategy and reactive power demands. The wind power plants should provide the reactive power exchange with the grid, due to the present high penetration level of wind power in the system. The exchange rate and level are specified by the transmission system operator.

Nowadays, Portugal has installed a capacity near 22% of the total installed capacity. In Fig. 1 it is shown the fault ride-through requirement for wind turbines in the Portuguese transmission grid. In Fig. 2 it is presented the grid support during faults by reactive current injection as stated in the Portuguese grid codes [1, 4].

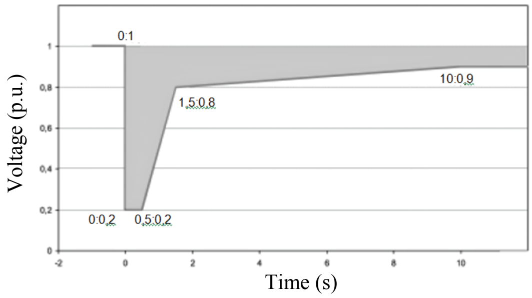

Fig.1. Fault ride-through requirement for wind turbines in the Portuguese transmission grid

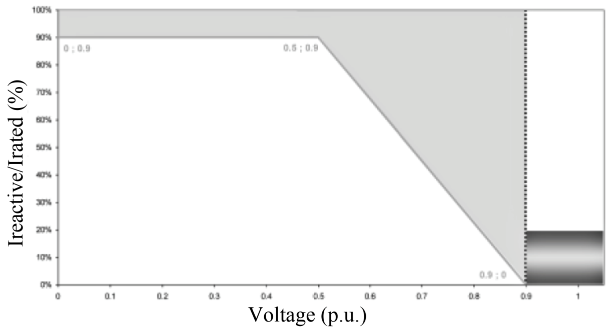

Fig.2. Grid support during faults by reactive current injection as specified in the Portuguese grid codes

In the disturbance period wind power plants are requested to restore the voltage level to the nominal value at the connection point, by injecting required amount of reactive current. Modern wind power plants are not allowed to disconnect during a network fault as long as the voltage in the connection bus is not lower than the voltage level specified in the grid codes [5].

Application Example

In Fig. 3, it is shown the modified Cigré Electric Power Network with 32 buses that was used in this study [6, 7]. The external system is simulated by means of three 380 kV infinite buses (N12, N15 and N16). Connected at this voltage level there are two important power stations, N1 and N10 (M1 and M2 with a rated power of 2000 MVA and M6 with 5000 MVA). A wind park with 990 MVA is connected at bus N17. The total power generated at the 380 kV is 7990 MVA, with 12.4% of wind power.

The total generation at 150 kV level is 500 MW (M3, M4 and M5). The total load of the system is 5000 MW and is mainly located at the sub transmission level (70 kV). The 70 kV loads are a mix of induction motor loads, constant impedance loads and compensation capacitors. The other loads were modelled as constant impedance type. The generators were modelled in detail. The automatic voltage regulators (AVR) of the generating units, the OvereXcitation Limiter (OXL) and the turbine speed governors (SG) were taken into account in the study. The 380/150 kV transformers have remote controlled taps. The 150/70 kV distribution transformers are fitted with automatic tap-changers regulating on the low voltage side. In this study the out-of-step and under voltage relays protecting the generating units were modelled.

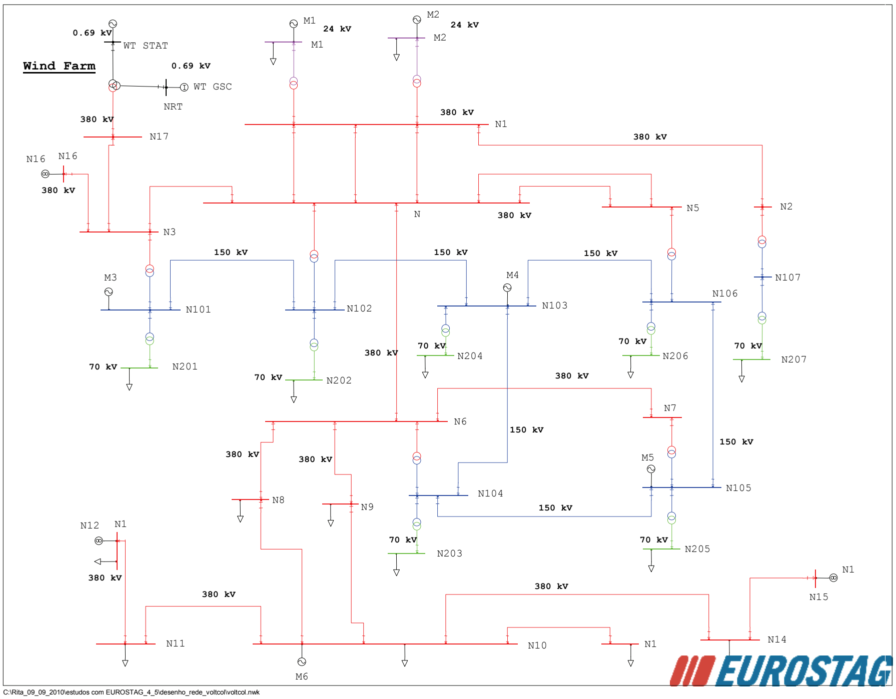

Fig.3. Grid Cigré test power network single line diagram

The wind farm is connected at bus N17 by a three winding transformer. The wind farm has 330 wind turbines each with 3 MW and is represented as an aggregated equivalent model.

Case Studies

Two different DFIG models were analyzed. Fig. 4 presents the global scheme of the first model (case I). The model of the DFIG is composed by the following [8]:

- Model of the doubly-fed machine and the converters;
- Aerodynamic model of the wind blades;
- Model of the wind turbine control (Pitch controller, Power controller and Main controller).

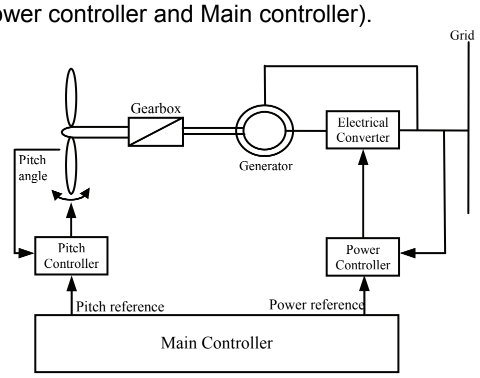

Fig.4. Model of the DFIG scheme (case I) [8]

In case I, the reactive power control scheme is disconnected. An automaton disconnects and reconnects the machine stator from the network if certain criteria are met, in order to protect the stator DFIG. In Fig. 1, it is shown the default values for the stator disconnection thresholds [4]:

- Terminal voltage below
  - 0.2 p.u. for at least 0.5 s;
  - 0.8 p.u. for at least 1.5 s;
  - 0.9 p.u. for at least 10 s.
- Output current above
  - 2 p.u. for at least 0.3 s.

In case II, a model with DFIG and crowbar and chopper was used. This model is different from the previous one (case I) in the modelling of internal protections of the machine (crowbar and chopper). The DC-link was modelled in detail, whereas it is considered as ideal and instantaneous in the model of case I.

Fig.5 presents the global control scheme of the model for case II, including the rotor crowbar and the DC-link chopper. The model of the DFIG is composed of the following parts [8]:

- Model of the doubly-fed machine and the converters;
- Model of calculation rotation speed and torque;
- Model of wind turbine control (power controller and main controller).

The most efficient wind parks now use technologies that allow them to stay connected during a fault and to produce again right after this fault. The model used takes into account these new technologies.

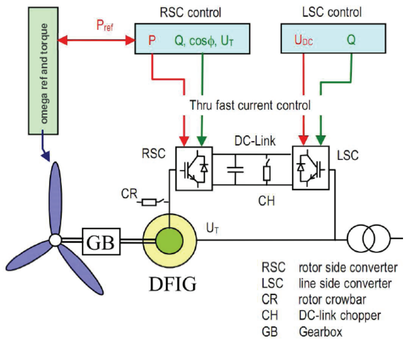

Fig.5. Model of the DFIG scheme (case II) [9]

Results

In both cases the following events were simulated:

- an increase of the wind speed from 7 to 25 m/s, from 20 s to 90 s;
- a contingency occurs at 100 s and the unit, M2 trips;
- a three-phase short-circuit occurs in the bus N1 at 300 s;
- at 300.25 s the three-phase short-circuit is remove;
- the tripping of the 380 kV overhead transmission line between buses N3 and N16 at 400 s.

In Fig. 6 it is shown the voltage variation in bus N17, where the wind farm is connected, for case I and II.

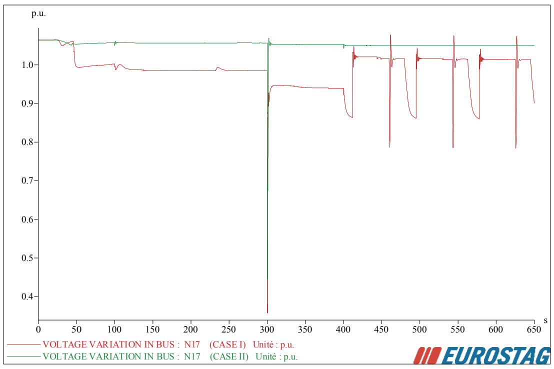

Fig.6. Voltage variation in bus N17 (case I and II)

Figs. 7 and 8 present the active and reactive power injected by the stator and the rotor of DFIG for case I, respectively. In this case after the three-phase short-circuit at 300 s, the DFIG stator protection is not activated. Nevertheless, after the tripping of the 380 kV overhead transmission line between buses N3 and N16, at 400 s, the DFIG stator protection is activated, since the voltage at bus N17 was below 0.9 p.u. for at least 10 s (Fig. 6).

When the protection stays open there is no longer active power generation by the stator and by the rotor of the DFIG. In this model there is no reactive power generation during the DFIG operation, although when the protection is activated the rotor will inject reactive power through the DC bridge into the network. This injection of reactive power will increase the voltage on bus N17 and the DFIG will be reconnected to the network. At this moment there is no longer reactive power generation and voltage decrease again, though the protective devices operate once more (Figs. 6 and 8).

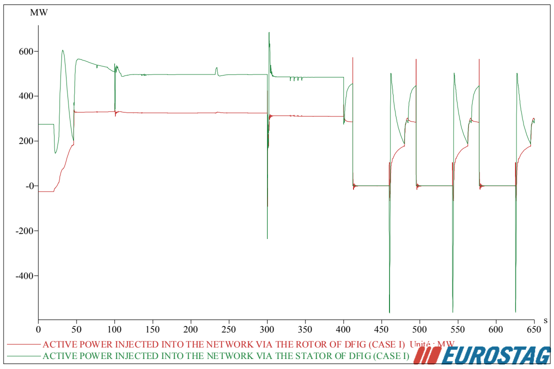

Fig.7. Active power injected by stator and rotor of DFIG (case I)

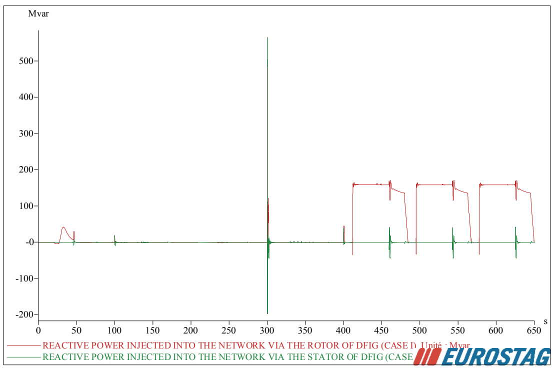

Fig.8. Reactive power injected by stator and rotor of DFIG. (case I)

Figs. 9 and 10 present the active and reactive power injected by stator and rotor of DFIG for case II, respectively. In this model of the DFIG the internal protections of the machine is made by the crowbar and chopper.

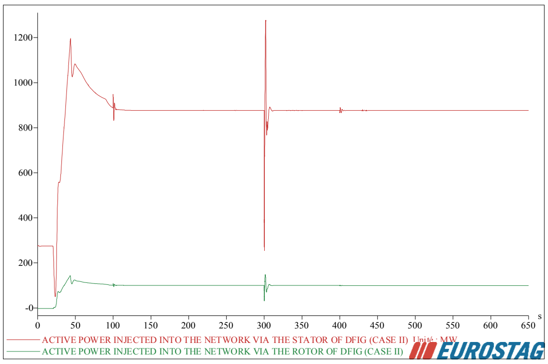

Fig.9. Active power injected by stator and rotor of DFIG (case II)

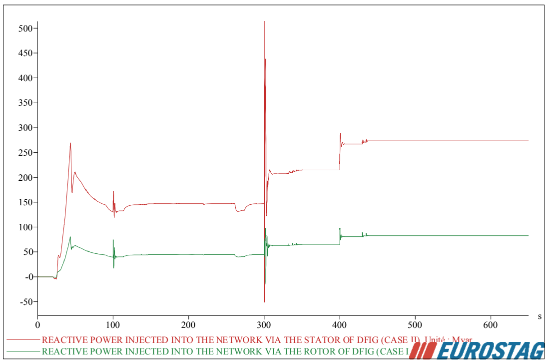

Fig.10. Reactive power injected by stator and rotor of DFIG (case II)

In Fig. 11 it is shown the field currents of M1 for case I and case II. After unit M2 tripping at 100 s, since M1 is closer to M2, it produces more reactive power. The OXL of M1 operates and the field current changes to its maximum value of 3 p.u., at 125 ms, in both cases. The three-phase short-circuit in bus N1 at 300 s produce the loss of synchronism of the unit M1 (Fig. 11).

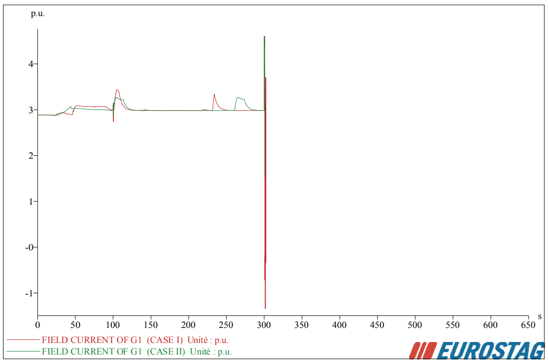

Fig.11. Field currents of M1 (case I and II)

Figs. 12 and 13 present the active and reactive power flow in transmission line between buses N16 and N3 for case I and case II, respectively.

For the voltage stability studies the voltage variation in buses N107 and N207 were chosen to exemplify the system trajectory, since the voltages at the other buses have a similar behaviour. In Figs. 14 and 15 it is shown the voltage variation at buses 107 and 207 for case I and II, respectively. The voltage rise at bus N207 implies an increase of the active and reactive power consumption in this bus. The 70 kV loads were modelled as a mix of induction motor and constant impedance. For this type of loads it was confirmed that the under load tap changer action will influence the transmission lines power transfer capability putting at risk the system voltage stability and as a result the voltage at bus N107 decrease.

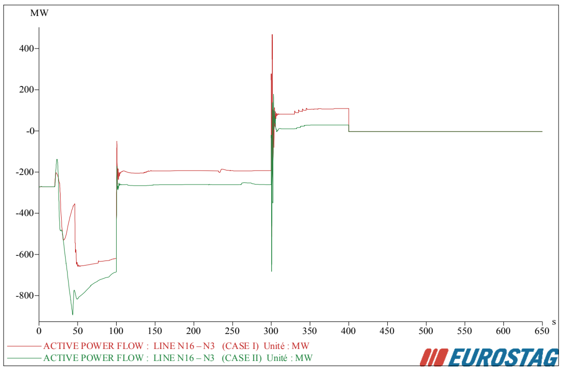

Fig.12. Active power flow in transmission line between buses N16 and N3 (case I and II)

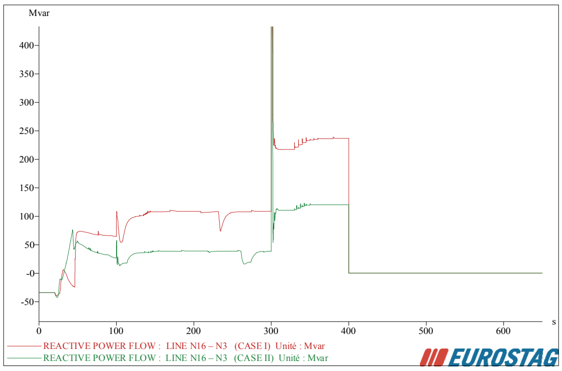

Fig.13. Active power flow in transmission line between buses N16 and N3 (case I and II)

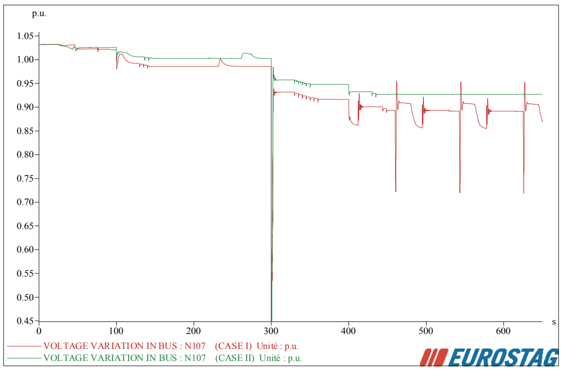

Fig.14. Voltage variation in bus 107 (case I and II)

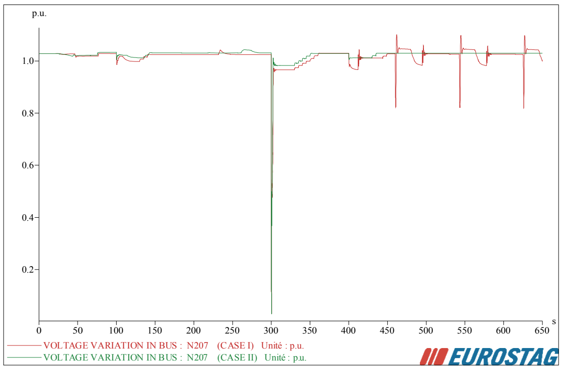

Fig.15. Voltage variation in bus 207 (case I and II)

Conclusions

This paper presents a study of the influence of the reactive power management for wind power plants in the dynamic voltage stability of a power network, considering two different schemes of DFIG models. The impact of the voltage ride through requirements of the grid codes and the grid support during faults by reactive current injection as stated in the Portuguese grid codes were considered and analyzed. In order to assess the power network voltage stability it was simulated several contingencies in different locations.

From the results obtained it was shown that wind turbines can be a source of reactive power to help the grid during contingencies. The bus voltage values are much more stable when the wind farm generates reactive power thus avoiding voltage stability problems. The crowbar and the chopper are two important features of the DFIG model. If the system is equipped with crowbar, the generator can accommodate very low voltages and can be reconnected rapidly. The power generation is only lost during the disturbance period and not after the clearance of the fault. On the other hand, the chopper allows the DFIG to stay connected for a longer time after a fault and it can produce reactive power the whole time, sustaining voltage levels.

From the TSO point of view this is an advantageous behaviour for the DFIG equipped with crowbar and chopper. It would be better if during the fault, more reactive power was produced and, after the fault, have a quick return of the bus voltage to its nominal value. The DFIG model with crowbar and chopper allows the TSO to ask for ancillary services like reactive power generation, during or after the fault.

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REFERENCES

[1] Regulamento da rede de transporte, Portaria n.º 596/2010, DR, 1.ª série, No.147, 30 de Julho, (in Portuguese)
[2] L. Lin, N. Zhou and J. Zhu, Analysis of voltage stability in a practical power system with wind power, Electric Power Components and Systems, (2010) Vol. 38, No. 7, 753-766
[3] M. Tsili, Ch. Patsiouras and S. Papathanassiou, Grid code requirements for large wind farms: a review of technical regulations and available wind turbine technologies, Proc. European Wind Energy Conference, Brussels, Belgium, (2008)
[4] J. Pinto, A. Pitarma, F. Batista and T. Rodrigues, Desafios e soluções para a integração de 7500 MW de potência eólica na rede portuguesa, XIII Encuentro Regional Iberoamericano de Cigré, May 24-28, (2009), (in Portuguese)
[5] C. Rahmann, H.-J. Haubrich, L. Vargas and M. B. Salles, Investigation of DFIG with Fault Ride Through Capability in Weak Power Systems, International Conference on Power Systems Transients, Kyoto, Japan, Jun. 3-6, (2009)
[6] R. M. Monteiro Pereira, C. M. Machado Ferreira and F. P. Maciel Barbosa, Dynamic Voltage Stability of an Electric Power Network with Double Fed Induction Wind Power Generators, Renewable Energy and Power Quality Journal, (2011), No.9, [online]. Available: www.icrepq.com/icrepq'11/593-monteiro.pdf
[7] M. Stubbe, et al., Tools for simulating Long Term Dynamics, CIGRE Task Force 38.02.08, ELECTRA (1995), No. 163
[8] Tractebel Engineering and Réseau de Transport d'Electricité, Eurostag Software user's Manual and Release Notes, (2010)
[9] I. Erlich, J Kretschmann, J. Fortmann, S. Mueller-Engelhardt, H. Wrede, Modeling of Wind Turbines Based on Doubly-Fed Induction Generators for Power System Stability Studies, IEEE Trans. on Power Systems, (2007), Vol. 22, No. 3, 909-919

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