Simulation of Two-Level and Multilevel Converters for Wind Power Systems: Analysis of Power Quality and Dynamic Stability

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1. Brief introduction

The general consciousness of finite and limited sources of energy on earth, and international disputes over the environment, global safety, and the quality of life, have created an opportunity for new more efficient less polluting wind and hydro power plants with advanced technologies of control, robustness, and modularity [1].

Power system stability describes the ability of a power system to maintain synchronism and maintain voltage when subjected to severe transient disturbances [2]. As wind energy is increasingly integrated into power systems, the stability of already existing power systems is becoming a concern of utmost importance [3]. Also, network operators have to ensure that consumer power quality is not compromised. Hence, the total harmonic distortion (THD) should be kept as low as possible, improving the quality of the energy injected into the grid.

The development of power electronics and their applicability in wind energy extraction allowed for variable-speed operation of the wind turbine. The variable-speed wind turbines are implemented with either doubly fed induction generator (DFIG) or full-power converter. In a variable-speed wind turbine with full-power converter, the wind turbine is directly connected to the generator, which is usually a permanent magnet synchronous generator (PMSG).

Variable-speed wind turbines usually employ active pitch control, where blade pitch angle increases reduce the captured wind power by reducing the angle of attack. The pitch control may have a considerable effect on the dynamical behaviour of wind generators. However, previous papers were focused mainly on the transient stability of variable-speed wind turbines at external grid faults [4]. Instead, this paper focuses on the transient stability of variable-speed wind turbines at a pitch control malfunction. Hence, we study the influence of a pitch control malfunction on the quality of the energy injected into the grid, analyzing the transient stability with different topologies for the power-electronic converters. Computer simulations obtained by using Matlab/Simulink are presented, and conclusions are duly drawn.

Key words: Power converters, wind turbines, power quality, dynamic stability.

2. Modelling

A. Wind Speed

The wind speed usually varies considerably and has a stochastic character. The wind speed variation can be modelled as a sum of harmonics with the frequency range 0.1–10 Hz [5]

$$u = u_0 \left[1 + \sum_K A_K \sin(\omega_K \, t) \right] \tag{1}$$

Hence, the physical wind turbine model is subjected to the disturbance given by the wind speed variation model [6].

B. Wind Turbine

During the conversion of wind energy into mechanical energy, various forces (e.g. centrifugal, gravity and varying aerodynamic forces acting on blades, gyroscopic forces acting on the tower) produce various mechanical effects [5]. The mechanical eigenswings are mainly due the following phenomena: asymmetry in the turbine, vortex tower interaction, and eigenswing in the blades. The mechanical part of the wind turbine model can be simplified by modelling the mechanical eigenswings as a set of harmonic signals added to the power extracted from the wind. Therefore, the mechanical power of the wind turbine disturbed by the mechanical eigenswings may be expressed by [6]

$$P_{tt} = P_t \left[1 + \sum_{K=1}^{3} A_K \left(\sum_{m=1}^{2} a_{Km} g_{Km} \right) h_K \right] \qquad (2)$$

where g_{Km} is given by

$$g_{Km} = \sin \left(\int_0^t m\omega_K \, dt + \varphi_{Km} \right) \qquad (3)$$

C. *Two-level Converter*

The two-level converter is an AC-DC-AC converter, with six unidirectional commanded IGBTs S_{ik} used as a rectifier, and with the same number of unidirectional commanded IGBTs used as an inverter.

D. *Multilevel Converter*

The multilevel converter is an AC-DC-AC converter, with twelve unidirectional commanded IGBTs S_{ik} used as a rectifier, and with the same number of unidirectional commanded IGBTs used as an inverter.

3. Control Method

Power converters are variable structure systems, because of the on/off switching of their IGBTs. The controllers used in the converters are PI controllers. PWM by SVM associated with sliding mode is used for controlling the converters.

Sliding mode controllers are particularly interesting in systems with variable structure, such as switching power converters, guaranteeing the choice of the most appropriate space vectors. Their aim is to let the system slide along a predefined sliding surface by changing the system structure.

4. Simulation

Fig. 1 shows the mechanical power of the wind turbine disturbed by the mechanical eigenswings, and the electrical power of the generator. A pitch control malfunction is simulated between 2 and 2.5 s.

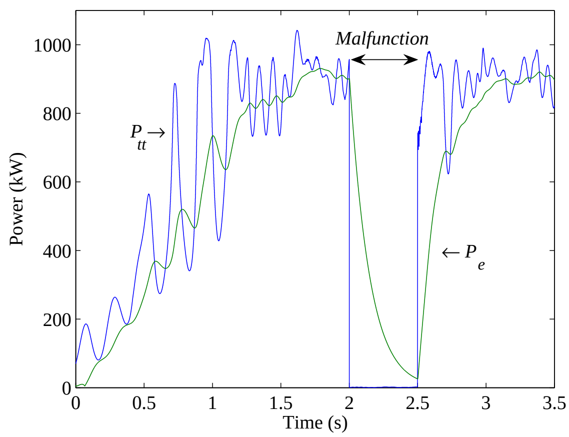

Fig. 1. Mechanical power and electrical power.

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