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Three-Level Converter in Offshore Wind Energy Systems: New Strategy for Unbalancing in Capacitors Voltage

M. Seixas[a,b,c], R. Melício[a,c,]*, V. M. F. Mendes[a,b], J. Figueiredo[a,c]

[a]*Universidade de Évora, Department of Physics, Évora 7004-516, Portugal*
[b]*Instituto Superior de Engenharia de Lisboa, Department of Electrical Engineering and Automation, Lisbon 1959-007, Portugal*
[c]*IDMEC/LAETA, Instituto Superior Técnico, Universidade de Lisboa, Lisbon 1049-001, Portugal*

Abstract

This paper is on an offshore wind energy conversion system equipped with full-power three-level converter and permanent magnet synchronous generator. Multi-level converters, namely three-level converters, are limited by unbalance voltage in the direct current link capacitors. A new control strategy for the selection of the output voltage vectors is proposed in order to improve balance of voltage in the capacitors.

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Keywords: Wind energy; variable speed; three-level converter; unbalanced voltage; modeling; simulation

1. Introduction

The demand for energy, the shortage of fossil fuels and the need for carbon footprint reduction have resulted in a global awareness of the importance of energy savings and energy efficiency [1]. The economic feasibility of offshore wind energy capturing depends on the favorable wind conditions on offshore as compared to sites on onshore or on the availability of land for onshore wind farm. The higher average wind speed available over sea waters [2] have to convey an economic value for offshore developments such that at least compensation is achieved for the additional cost, including an estimate for the operation and future maintenance costs. Also, if the feasibility on onshore is deeply compromised by the infeasibility on the use of land space, the exploitation offshore might be promising.

* Corresponding author. Tel.: +351-266-745-372; fax: +351-266-745-394.
E-mail address: rmelicio@uevora.pt

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The increasing share of wind energy in power generation will change considerably the dynamic behavior of the power system due to the intermittency and variability characterizing the eolic source of energy. The increasing share of wind energy in power generation may lead to a network operation with an eventual reduction on power system frequency regulation capabilities [3]. Network operators have to ensure that consumer power quality is not compromised [3]. Hence, due to the increased wind power penetration new technical challenges emerge concerning dynamic stability and power quality entailing research for more realistic and accurate physical models.

Power electronic converters play a crucial role in the integration of wind power into the electric grid [2]. However, multilevel converters, namely the three-level converters, are limited by the following drawbacks: voltage unbalance, high component count, and increased control complexity [4]. A critical issue reported for three-level converters is the design of the DC-link capacitors in order to accommodate enough preventing of the eventual voltage unbalance, i.e., special attention should be paid to the unbalance voltage of the capacitors in three-level converters, because the unbalance may lead to undesirable control malfunction.

The strategies for mitigating capacitor voltage unbalance can be described by a classification into two groups identified respectively by the additional hardware installation [5-8] and by the sophisticated switching control [8]. The additional hardware is proposed to inject/extract current to/from capacitors. However, the augmented system cost and complexity, particularly at high voltage/power levels is increased [9]. The switching control strategy is based either on adjustable pulse width modulation (PWM) techniques [10], or on space vector modulation techniques [3,9,11-14]. In [10] a strategy of adjusted triangular carrier signals is used to obtain the switching sequence. In [9] a quadratic cost function based on the minimum energy property of the capacitors associated with the voltage deviations of the DC capacitors is used to select the best adjacent switching states. In [11] an algorithm based on the redundant positive and negative small vectors is used to adjust their sequencing and duty cycle. In [12] an optimal predictive controller based on a quadratic cost function designed to minimize the AC current errors, the voltage balancing and the semiconductors switching frequency is used to find the vector closer to the desired optimum. These strategies are reported to be requiring high computational power and increasing the switching frequency of the power semiconductors [14].

A new method is presented in [14] by taken a convenient advantage of the redundant space and by the use of the DC average power flow direction. The strategy takes into consideration each capacitor voltage error, computed by the difference between the capacitors total voltage divided by the total number of capacitors and by the measured capacitor voltage. The sliding mode chooses the appropriate space vector which may have redundancy. The active capacitors are computed for the each redundant space vector as well as their voltage error. If power flows to/from the DC bus is chosen, the redundant switch configuration uses the capacitor groups presenting the highest/lowest error voltage. The appropriate space vector which may have redundancy is chosen in [3] by the sliding mode. The control strategy implements two selecting tables according to the unbalance of the capacitors. If the voltage on the upper capacitor is higher, then the space vector is chosen from the table which has the redundant vectors that will charge the lower capacitor and vice-versa. An observation about the similarities of the strategies presented in [14] and [3] reveals that the authors use the same principle, but although the strategy proposed [3] is characterized by presenting a processing with less complexity, the mitigation of the unbalance capacitor voltage in the presence of occurrence of fast wind dynamics is compromised.

In this paper, an offshore wind energy conversion system (OWECS) in deep water equipped with a variable-speed wind turbine, a permanent magnet synchronous generator (PMSG) and a three-level converter is modeled using a new converter control strategy for the selection of the output voltage vectors. Simulation studies are carried out in order to evaluate the performance of the three-level converter with a new strategy based in a method different from the one proposed in [3] due to the fact of taking a further step involving the use of three selecting vector space tables, allowing to take into account both external and internal hexagons formed by the output voltage vectors. The method proposed is capable of mitigating unbalance capacitor voltage in the presence of an occurrence of a fast wind dynamic.

The rest of the paper is organized as follows. Section 2 presents the configuration and the modeling used for OWECS, considering the wind speed variation modeled by a sum of harmonics, a three mass drive train. Section 3 presents the control strategy based on PI and pulse width modulation by space vector modulation associated with sliding mode to control the converters. Section 4 presents some of the used data and the simulation results. Finally, concluding remarks are given in Section 5.