Designing the Next Generation of Computational Codes for Wind-Turbine Simulations

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ABSTRACT
A strategic study was performed to assess present computational solutions for the realistic simulation of offshore wind turbine installations. Three critical issues were identified that make it desirable to implement a new simulation code. Current numerical codes are not efficient enough, there does not exist a convincing implementation of hydrodynamical effects and mooring system dynamics, and it is difficult to extend existing codes with novel approaches. To tackle these issues, a hybrid computational approach is proposed that takes new developments in commodity computer hardware into account.

KEY WORDS: Offshore wind turbine; hydrodynamics; numerical simulation; floaters; general purpose graphics processing units; parallel computing.

INTRODUCTION
Numerical simulation is the main tool with which complicated physical systems can be analyzed. This is especially true with regard to wind turbine installations, which are systems subject to a number of complex forces and nonlinear behaviors. Simulation is not only used for the design and the certification of structures, but also for the purpose of studying specific effects and properties (both in an industrial and academic context), and for optimization tasks. In all these areas of application, a computational solution needs to model and capture all relevant influences and properties of the system under study. Moreover, computer codes should be flexible enough to allow for later modifications, and efficient enough to allow for nontrivial studies, e.g., involving long simulation times or many different parameter settings (Oliveira and Stewart, 2006).

Regarding offshore wind turbines, there exist a number of computational codes and simulation environments that have found widespread use (see below for some influential examples). These are almost exclusively based on onshore wind turbine simulation, and are now being adapted to encompass the offshore environment. The main challenge here lies in a realistic description of hydrodynamical effects (Cordle, 2010). Especially for floaters with large-volume buoyant members, radiation and diffraction effects contribute significantly, and in a complex geometry-dependent way. One solution has been to employ dedicated hydrodynamical multi-body codes, developed for marine engineering applications, and couple them with existing wind turbine simulation codes (Skaare et al., 2007), but this approach is of limited applicability.

The main problem with current simulation approaches is their low efficiency. A ratio of 1:1 between simulated and simulation time is about the current state-of-the-art for time-domain simulations. This is unacceptable for optimization studies and many other problems. Related challenges are described and a solution is proposed below.

CURRENT CHALLENGES
Aerodynamics
Current modeling of wind turbine aerodynamics is largely based on blade element momentum theory (Glauert, 1935; Leishman, 2006; Hansen, 2008), in which the blade is divided into a number of elements and the induced velocities on each element are calculated individually from simple balance equations. Correction factors are introduced to account for tip-loss effects. This is the working horse of modern wind turbine simulation and has been validated in numerous studies.

The limitations of blade element momentum theory are well known: it is not applicable in highly unsteady flow and under yawed conditions. The former is a consequence of the assumption of independence between blade elements, the latter a consequence of the actuator disk assumption behind the momentum theory. In order to address such situations, one interesting possibility is the use of more accurate models for the calculation of induced velocities. A conceptually elegant method is the use of vortex methods, i.e., Lagrangian approaches to flow field calculations derived, but not limited to, from potential theory (Katz and Plotkin, 2001). These methods are general enough to address all relevant simulation scenarios, including the aerodynamics of vertical-axis machines (Paraschivoiu, 2002). Three well-known examples that have been coupled to wind turbine simulations are the AWSM code developed at the Energy Research Centre of the Netherlands (van Garrel, 2003; Kaufer, 2007), the GENUVP code developed at the National Technical University of Athens (Voutsinas, 1995), and the prescribed vortex model implemented in some versions of AeroDyn (Currin et al., 2008). There are many interesting aspects about these methods that cannot be considered here (cf. Cottet and Koumoutsakos, 2000). The main drawback of these methods is their speed, which results in simulation times about two orders of magnitude longer than with blade element momentum theory (but see below).