Chapter 52

Optimization of Small Wind Turbines Using Genetic Algorithms

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ABSTRACT

This paper presents a detailed optimization analysis of tower height and rotor diameter for a wide range of small wind turbines using Genetic Algorithm (GA). In comparison with classical, calculus-based optimization techniques, the GA approach is known by its reasonable flexibilities and capability to solve complex optimization problems. Here, the values of rotor diameter and tower height are considered the main parts of the Wind Energy Conversion System (WECS), which are necessary to maximize the output power. To give the current study a practical sense, a set of manufacturer’s data was used for small wind turbines with different design alternatives. The specific cost and geometry of tower and rotor are selected to be the constraints in this optimization process. The results are presented for two classes of small wind turbines, namely 1.5kW and 10kW turbines. The results are analyzed for different roughness classes and for two height-wind speed relationships given by power and logarithmic laws. Finally, the results and their practical implementation are discussed.

INTRODUCTION

In the last few years, the demand for wind energy was dramatically increased. As a result of this upsurge, wind farm operators are pressed more than ever to get the most out of their power generation equipment. The aim of the optimization process is not only to make the wind farms more profitable, but also to guarantee an adequate flow of power for longer times. However, this task is not simple because the wind is a fluctuating non-conventional source of energy. Therefore, most of the wind energy studies

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consider the wind velocity as a random variable determined by the Weibull distribution characteristic (Karaki et al., 1999).

The wind turbine output is proportional to the product of the cube of the wind speed and the rotor swept area. Therefore, the accurate selection of the rotor diameter is a very important step in wind turbine optimization processes. On the other hand, the wind speed increases with the turbine height even in lower wind areas (Patel, 1999; NREL, 2002). Since the wind speed, \( V \), increases with the hub height, \( h \), and the rotor diameter \( D \) affects the power output, it is necessary to optimally select those wind turbines, which have suitable tower heights and blade lengths. This approach leads to a maximum ratio of the output power to the total cost of the turbine including blades and tower.

Despite the significant achievements in WECS optimization, a number of drawbacks still exist in this field, causing a serious restriction in the system utilization. One of these drawbacks is the reliance of many optimization studies on pure theoretical and direct techniques (Frair, 1981; Shuhui et al., 2001). Unfortunately, most of the problems in the field of wind energy are so complicated that they cannot be solved by these techniques. Among these problems is the variety of features that have to be brought together into a feasible context and the individuality of the wind sites, where the energy output is characterized by a number of site-specific parameters. Therefore, the conventional optimization studies were only able to deal with one WECS component (Wood, 2001) or to introduce many assumptions and approximations to optimize several components (Frair, 1981; Shuhui et al., 2001; Morgan and Garrad, 1988).

In the present work, GA is employed to overcome the above mentioned optimization difficulties, using actual data of real wind turbines. The approach is based on a direct relationship between power output and the joint effect of tower height and rotor diameter. The cost function is a combination of maximizing annual energy production and minimizing the cost of the blades and tower. The objective functions and constraints are derived for power law and logarithmic law. These relationships are then used to determine the optimum tower height, \( h_{opt} \), and optimum rotor diameter \( D_{opt} \), for different roughness classes. Finally, a detailed comparison between the results of the power law approach and the logarithmic approach is provided.

**BASICS OF GENETIC ALGORITHMS**

Genetic algorithms are different from other heuristic methods in several ways. The most important difference is that a GA works on a population of possible solutions, while other heuristic methods use a single solution in their iterations. Another difference is that a GA is a probabilistic approach, and not deterministic. Each individual in the GA population represents a possible solution to the problem. The suggested solution is coded into the “genes” of the individual. The values and their position in the “gene string” tell the genetic algorithm what solution the individual represents.

By applying the rules of evolution to the individuals, it is possible to find one set of individuals, which can be combined to new individuals. Using this method repeatedly, the population will evolve good solutions. Specifically, the elements of a GA are: selection (according to some measure of fitness), cross-over (a method of reproduction, “mating” the individuals into new individuals), and mutation (adding a bit of random noise to the off-spring, changing their “genes”).

Many studies have demonstrated, via theoretical and experimental approaches, the advantages of GA over traditional optimization techniques (Grady et al., 2005; Park et al., 1996). As the size and complexity of the design problem increases, classical methods of optimization start to have various difficulties.
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