WIND FARM LAYOUT OPTIMIZATION WITH GENETIC ALGORITHMS AND GEOGRAPHICAL INFORMATION SYSTEMS

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1. Introduction

Wind has become the renewable energy source which has been developed the most in the last few years. The increase in the prices of conventional energy sources, the threats derived from climatic change and the incentives offered by authorities have driven the development of this energy source and wind farms have been installed all over the world.

The design of a new wind farm requires several phases, one of the most important being, the selection of the locations for each one of the wind turbines of the wind farm. This selection affects the economic operation of the wind farm. In order to reduce wake effect among wind turbines they must be spaced as far apart as possible in the prevailing wind direction. The wake effect represents the losses in wind energy when it crosses a wind turbine. On the other hand economic factors can force the reduction of the distance between adjacent wind turbines; factors such as the cost of the land covered by the wind farm or the construction of the auxiliary infrastructures (roads, connection to the electric grid, etc.). The selection of the locations for wind turbines is generally made by the designer on a trial and error basis, helped by specific software tools for evaluating the final energy production. The availability of optimal sitting selection tools may help in the design of wind farms, reducing time and effort. Some works have been published, describing some of these tools based on an optimization process ruled by evolutive algorithms [1, 2].

Geographical Information Systems (GIS), software technologies developed for spatial data analysis, are suitable tools for solving these problems, and they allow for the simultaneous evaluation of key technical, economic, and environmental factors [3]. Most of GIS programs include a set of useful functions (lowest cost path search, for example) and can be programmed to incorporate new ones. The processing and visualization capabilities of GIS and the systems' ability to manipulate geographic data make them suitable for optimizing wind farm layouts.

This paper presents the implementation of a wind farm optimization tool, which is able to find the best locations to place the wind turbines in the area selected for the installation of the wind farm. This tool is based on genetic algorithms [4], using as the fitness function the expected annual electric energy production in the wind farm.

Keywords: wind farm design, genetic algorithms, renewable energy planning.

2. Description of the proposed tool

The selection of optimal locations for the wind turbines of a wind farm (wind farm optimal layout) can be automated with GIS using the following methodology. The objective is to find the best places for a fixed number of wind turbines in the available terrain for the construction of the wind farm. In this case, the best locations are considered to be those which offer the maximum electric energy production. The flowchart of the proposed methodology is shown in Figure 1, which is based on the next steps:

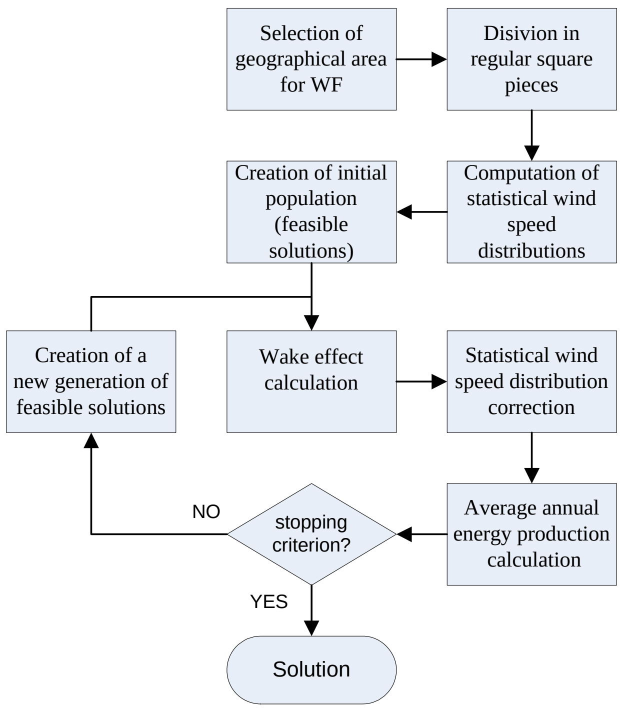

Fig. 1. Flowchart of the proposed methodology.

1. The available surface for the construction of the wind farm is divided into regular pieces (squares) with a selected resolution (size). This structure represents the grid for the locations of the wind turbines.
2. With measured data obtained from the weather station nearest to the location of the wind farm, wind resources are calculated for all the surface square pieces corresponding to the available surface. For this process we have used WASP (Wind Atlas Statistical Package) software, which has provided us with the parameters of the probability distribution of wind speed (Weibull distribution, with the shape and the scale parameters), for all the square pieces, and for twelve sectors, each 30 degrees wide, according to the wind direction. Also, the portion of wind speeds corresponding to each sector was provided.
3. An initial population is generated randomly. Each individual in the population corresponds to a feasible solution for the wind turbine locations. In order to improve the speed in the achievement of proper solutions, some of the individuals in the first population can be initially selected (for example, uniform spread of wind turbines in the available terrain).
4. For each individual in the population (feasible solution), the wake effect among wind turbines is calculated taking as base the parameters of the probability distribution of wind speed for the first wind turbines in each one of the considered sectors. Using these parameters a vector with 5000 elements (wind speed in that sector) is obtained and projected to the locations of the wind turbines that are downwards. The probability distribution parameters for the wind speed in these wind turbines are corrected according to the results of the wind speed series generated for their locations. In this correction process, the roughness and orography of the terrain are taken into account.
5. For each individual in the population, the average annual energy supplied by the wind farm, *AES*, is computed by means of (1), where $pc(v)$ represents the manufacturer's power curve of the selected type of wind turbine (power generated as a function of the wind speed); the wind speed probability Weibull distribution $wb_i(v)$ for i-th wind turbine; a factor, f_s, which represents the portion of wind speed data corresponding to the sector s; and the cut-in wind speed, v_1 (minimum wind speed with power generation) and cut-out wind speed, v_2 (maximum allowed wind speed) corresponding to the selected type of wind turbine. The number of wind turbines that compose the wind farm are *N*.

$$AES = \sum_{s=1}^{12} 8760 \sum_{i=1}^{N} f_s \int_{v_1}^{v_2} pc(v) wb_i(v) dv \qquad (1)$$

6. All the individuals in the population are ranked according to the average annual energy supplied (fitness function) to create a random roulette. If the stopping criteria are not accomplished, a new population is created using the genetic operators (next generation), following the execution in step 4.

Each individual is coded in a string composed of digits (from 0 to 9). Each wind turbine corresponds to 6 digits which contain the location of the wind turbine. The first three digits represent the row in the grid created in step 1; the second three digits represent the column in the grid.

The genetic operators used are: the crossover operator, which randomly interchanges a set of digits between two selected individuals; the mutation operator, which randomly changes the value of also randomly selected digits in an individual.

The stopping criteria can be any of the following: maximum number of generations, maximum number of generations without improvement, solution with a minimum value of *AES*, elapsed time, etc.

3. Conclusions

This paper presents the methodology followed by a new tool based on an optimization process ruled by a genetic algorithm for the selection of locations to put in place the wind turbines of a new wind farm. The tool uses geographic information and wind speed probability distributions in order to select the locations with the largest electric energy production. The tool has been implemented in a GIS platform allowing high visual and computational capacities. The proposed wind farm layout optimization tool has been tested with several examples showing good results when compared with those ones obtained from computer programs such as WASP with different wind park layouts.

Further research is currently being performed by the research group to improve the characteristics and capabilities of the planning tool described in this paper, with the inclusion of the optimal location for the electric power station of the wind park, selection of paths for the electric connection from each wind turbine to the power station, etc.

References

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