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# ROTOR PARAMETER OPTIMIZATION OF WIND TURBINE

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***Abstract***—*The optimization criteria of wind turbines rotors are determined.. It is proposed the hybrid scheme based on multicriteria genetic algorithm and Pareto's local descent for the solution of given problem.*

**Index terms**—Wind turbine; rotor; multicriteria optimization genetic algorithm; Pareto's local descent.

## I. INTRODUCTION

Wind is a renewable, plentiful and widely distributed source of energy that has proved to be an excellent solution for the need to generate mechanical power.

Wind energy is the fastest growing source of electricity in the world. In 2015, nearly 45.000 MW of new capacity were installed worldwide. This stands as a 10 percent increase in annual additions compared with 2014.

The success of the implementation of renewable energy systems has been driven by policy support that has grown considerably during the last decade .Either focused on utility-scale or small-scale generation systems, policies continue to evolve in order to address market developments and reduce costs to promote massive installation. The EU 2020 Climate and Energy Package is an example of policy making in Europe, consisting of a set of binding legislation which aims to ensure that the European Union meets its targets for 2020: achieving 20 % reduction in greenhouse gas emissions from 1990 levels; raising the share of renewable energy consumption to 20 % and making a 20 % improvement in EU's energy efficiency.

Turbine technological improvements have been one of the main reasons for the significantly increased capacity of the past decade, but even with such improvements turbines must be properly maintained to achieve optimal production and meet revenue targets. Nowadays, monitoring is indispensable to ensure that the turbines are operating at optimum conditions and maximum performance.

## II. PROBLEM STATEMENT

Search of the optimal turbine blades profile geometry analytically is impossible due to nonlinearity of Navier–Stokes equations.

The main criteria for the optimization of wind turbines parameters in multicriteria problem are a number of aerodinomic, electrical, electromechanical characteristics with appropriate boundary conditions, as well as economic parameters.

Assume the following geometric characteristics of the blade profile as variable parameters: the maximum profile thickening; the curvature radius of the profile midline; maximum thickening position with respect to the chord center; as well as an array of points, describing the geometry of the profile.

In general, the multiobjective optimization problem includes a set ***N*** of parameters (variables), a set **K** of objective functions and constraints set **M**. Objective functions and constraints are functions of the variables.

Thus to solve multicriteria task it is necessary to find an optimum on the **K** criteria, and the task itself is formally written as:

$$y = f(x) = \left(f_1(x), f_2(x), \ldots, f_K(x)\right) \to \text{opt},$$

$x = (x_1, x_2, \ldots, x_N) \in X$ – is a solution vector satisfying the constraints **M**, $g(x) = (g_1(x), g_2(x), \ldots, g_M(x)) \geq 0$; $y = (y_1, y_2, \ldots, y_K) \in Y$ – is an objective functions vector.

Here $X$ is a solution space and $Y$ is aims or criteria space. Limits $g(x) \geq 0$ define the set of allowable solutions of the task.

Allowable set **D** is defined as a set of solution vectors **x**, that satisfy the constraints $g(x)$:

$$\mathbf{D} = \{\mathbf{x} \in \mathbf{X} \mid g(x) \geq 0\}.$$

Then allowable area in the aims space $D$ image is denoted through $Y_f = f(D) = \bigcup_{x \in D} \{f(x)\}$.

## III. REVIEW

Wind turbine optimization is multi-criteria, multi-extremum task, the solution of which requires the use of deterministic and stochastic methods of nonlinear programming. The paper [16] presents a model of multicriteria optimization of the wind turbine, which is to address the increasing energy performance and minimize turbine operating loads. The result of that work was the design of horizontal axis three-bladed turbine of minimum value. The key technique is the use of various algorithms to optimize the parameters of the turbine and blade geometry optimization.

Review of a number of works devoted to computer-aided turbomachinery design is given in [1]. In this paper, the authors proposed the approach to automatically optimize the flow of the hydraulic turbine impeller based on the solution of a sequence of impeller blade flow problems and search of such blade form that provides minimum of any one given objective functional. The basis of the optimization algorithm in [2], as in the majority of work on impellers optimization, is the genetic algorithm demanding the calculation of the flow in the impeller for several thousand blade geometry variations.

Genetic algorithms for multiobjective optimization start to be widely used in automatic design of turbomachinery problems [3], [4].

The paper [3] is devoted to the optimization of the impeller geometry of Kaplan [4], [5] and Francis hydraulic turbines. In [4] the problem of the steam turbine vane optimization is solved. In the above works hydrodynamic calculations are based on the Navier–Stokes incompressible fluid equations and for turbulence modeling $k$–ε-model is used. Hydrodynamic calculations in [6] – [8] are performed using commercial software. In paper [2] losses in the impeller for turbine's different modes of operation are minimized. Optimization calculations in [9], [10] are based on the use of parallelized genetic algorithm.

According to [4] there are more than 20 multi-criteria optimization methods in mathematical programming. But generally they can be divided into 3 basic most commonly used approaches to the formation of the Pareto set:

1. Ranking of the partial criteria by importance (priority) and their consecutive application.
2. Definition (highlight) of the main criteria and transfer of other partial criterion functions into constraints.
3. Construction of the generalized criterion as a convolution of partial criteria.

Genetic algorithms belong to the class of evolutionary algorithms and possess a number of characteristics that make them more preferred than classical optimization methods [4]:

– implementation of effective solutions search via genetic algorithms do not require specific knowledge of the problem and its parameters;

– in genetic algorithms instead of deterministic operators stochastic ones are used, and they have proved to be quite resilient in a noisy external environment;

– the inherent parallelism of genetic algorithms – simultaneous consideration of a large number of the individuals in population – makes them less sensitive to local optima and noise impact.

## IV. MULTICRITERIA OPTIMIZATION PROBLEM SOLUTION

As genetic algorithms belong to the multi-point search methods, optimization problem with them can be solved even in case of the multimodal nature of the objective functions. Moreover, they are also applicable to the problems with discrete search space. Therefore, genetic algorithms are one of the most powerful optimization mechanisms, while fairly simple in use [11] – [15], [17].

Algorithms based on an evolutionary approach to the multicriteria tasks solution can get rid of the main disadvantages of the classical methods, as are appropriate for large-scale problems and able to grab a Pareto-optimal points, even after a single algorithm iteration. By sustaining the solutions population and making use of the concept of Pareto optimality, evolutionary algorithms can process a variety of Pareto-optimal solutions in parallel. So, unlike most classical approaches to multicriteria optimization, when for every single point you must make a separate iteration of Pareto-optimal solutions search algorithm, the application of evolutionary approach to vector optimization through incorporated in genetic algorithms multimodal search, you may receive different Pareto set points in a single run of the algorithm. This fact is a clear advantage of evolutionary approach to solving the problems of multicriteria optimization over traditional methods of solving them. As a result, genetic algorithms are very effective means of solving optimization problems, especially problems with vector criterion.

The genetic algorithm used for a particular purpose shall consist of the following main components [4].

1. Representation of potential solutions to the problem.
2. The method, which creates an initial population of possible solutions.
3. Solutions evaluation function, which plays the role of the external environment, determining solutions in terms of their suitability.
4. Genetic operators that change the composition of the children (descendants).
5. The values of various parameters that are used by genetic algorithm (population size, the probability of genetic operators being applied, etc.).

In the development of specific methods for solving problems of multicriteria via genetic algorithm, the emphasis is on the modification of purpose suitability and selection with maintenance of the population diversity stages.

The most effective approach for the solution of this problem is SPEA (Strength Pareto Evolutionally Algorithm) method [18] in which:

- to assign individuals a scalar value of fitness Pareto dominance concept is used;
- individuals non-dominating with respect to other members of the population are stored externally in a special external set;
- to reduce the number of individuals stored in an external set, clustering is performed, which in turn does not influence the process of searching the acquired properties in individuals.

SPEA uniqueness and advantages of the method lies in the fact that:

- it combines the above approaches in a single algorithm;
- fitness of each individual in the populations in this method is determined only with respect to the external set individuals regardless of whether the individuals in population dominate each other;
- despite the fact that the “best” individuals obtained in the previous generations are stored separately – in the external set – they are still involved in the selection;
- and to prevent premature convergence the SPEA method uses a special mechanism for the formation of niches where the division of general fitness is carried out not in the sense of distance between individuals but based on Pareto dominance.

In solving the conditional multiobjective problem the final points should not just get in the Pareto set but comply with constraints – to lie in the allowable area. In this case, depending on the location of the allowable area in the search space, obtained Pareto-decision of conditional problem can change relatively to unconstrained problem solution.

## V. HYBRID ADAPTIVE ALGORITHMS FOR MULTICRITERIA OPTIMIZATION

The most commonly the various combination (hybridization) of several different approaches are used which, in most cases, can significantly improve the results with respect to individual application of the methods. Each one included in the hybrid algorithm is aimed at solving specific subtasks. Hybrid schemes itself consists of a sequence of inclusion stages of one or another separate approach, allowing to accumulate at a certain stage of the problem solution positive properties of each of the algorithms. An important role is played by the organization itself of interaction of several algorithms that make up the hybrid, in particular, the order of their inclusion with respect to each other.

To eliminate the flaw detected in SPEA method in unconditional multicriteria problems solution - the presence in the final non-dominating set non-Pareto points it is offered to make “treatment” (specification) of that non-dominating points obtained after the stop of genetic algorithm which does not belong to the Pareto set. Due to the fact that decisions in genetic algorithms are represented as binary strings for the “treatment” of non-dominating points seems very convenient the use of the Pareto local search algorithm, acting in the space

In the case of multicriteria problems we are dealing with so-called Pareto local search (PLS). It is distinctive feature is a way to determine the best solutions – comparison of neighboring points. In this case, the determination whether the point, obtained at this stage, is better than the last received before that based on Pareto principle, i.e. transition to the next point is carried out, if it is dominating current by a set of criteria.

Thus, to solve the problems of unconstrained multicriteria optimization is proposed to use a hybrid adaptive search algorithm that combines evolutionary algorithm SREA and Pareto local search.

The hybrid scheme of evolutionary algorithm multicriteria optimization can be represented as a sequence of the following steps.

1. The solution of problem by original SPEA method.
2. Clarification received after genetic algorithm stopping of pseudo-non-dominating points of resulting population using Pareto local search procedures.
3. Elimination of possible points clots using cluster analysis.

Hybrid evolutionary algorithm for unconditional optimization developed above was chosen as a basic algorithm for solving conditional multicriteria optimization.

To allow the problem solution by the conventional methods of multicriteria optimization, each constraint is treated as a separate objective function and therefore originally conditional problem (with one or more criteria – objective functions) eventually reduced to unconditional multicriteria optimization problem. That is, the initial problem is represented as a set of criteria: initial objective functions plus an additional criteria – the degree of constraints violation. Thus, the problem of the conditional multicriteria optimization is transformed and takes the following form.

*Initial problem*: objective functions – $F(X) \to \text{opt}$, constraints – $G(X) \leq B$;

*Transformed task*: objective functions: $F(X) \to \text{opt}$, $|G(X) - B| \to \text{opt}$.

The reduction of the conditional to the unconditional problem and its solution by multi-criteria hybrid SPEA + PLS does not properly solve the problem of finding the Pareto set: after the completion of the genetic algorithm the non-dominating points are obtained, some of which are satisfying restrictions and some are unacceptable points. In order to bring the unacceptable point to acceptable, their improvement is performed by a standard local descend in Boolean variables space. Since it is not known in advance that by applying the "treatment" of points we'll get a real improvement, in viewing the neighborhood the transition to first improvement strategy is used in the developed algorithm. The procedure of improving points by local search already takes into account the original problem objective functions. Next, points which could not be "treated" are discarded, and the remaining populations of individuals are allowable by constraint functions.

In the last step of the conditional multicriteria optimization problems solution algorithm, according to a hybrid SPEA + PLP algorithm suggested above, received valid point undergo the procedure of improvement by using the Pareto local search and elimination of possible clusters of points with the help of cluster analysis. Because allowed individuals can not be dominated by unacceptable, improvement occurs only on objective functions of the initial problem. As a result of the application of the algorithm to the final point of concentration is the point (*s*) conditional optimum.

Block diagram of the described above conditional multicriteria optimization problems solution algorithm is shown in Fig. 1.

Obtained in result of suggested algorithm execution approximation of the Pareto set is representative – points are evenly distributed, no condensation, no dominating points.

## V. CONCLUSIONS

It is shown that rotor parameter optimization of wind turbines is a multicriteria problem. Based on the analysis it is substantiated that the most effective approach is the use of hybrid algorithm adopted to the solution of conditional multicriteria problems.

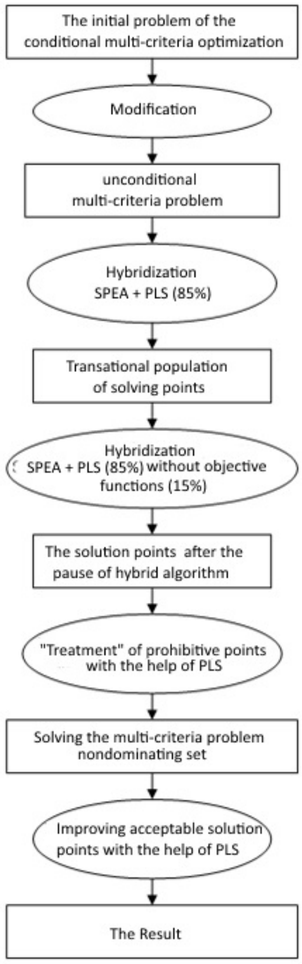


Fig. 1. Scheme of adaptive search algorithm for solving multicriteria conditional optimization problems

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**В. М. Синєглазов. Оптимізація параметрів ротора вітроенергетичної установки**

Визначено критерії оптимізації роторів вітроенергетичної установки. Запропоновано гібридну схему на основі багатокритеріального генетичного алгоритму та Парето локального пошуку.

**Ключові слова:** вітроенергетична установка; ротор; багатокритеріальна оптимізація; генетичний алгоритм; Парето локальний пошук.

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**В. М. Синеглазов. Оптимизация параметров ротора ветроэнергетической установки**

Определены критерии оптимизации роторов ветроэнергетической установки. Предложена гибридная схема на основе многокритериального генетического алгоритма и Парето локального поиска

**Ключевые слова:** ветроэнергетическая установка; ротор; многокритериальная оптимизация; генетический алгоритм; Парето локальный поиск.

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