Comparison of hybrid metaheuristics for a direct load control problem

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Keywords: Multi-objective optimization, GRASP, Simulated Annealing, outranking relations, ELECTRE TRI, direct load control problem.

1 Introduction and motivation

The complexity and the dimension of multi-objective optimization (MOO) problems, particularly due to the combinatorial nature and the characteristics of the search space, require suitable methodological and computational tools. In recent years, the use of metaheuristics in the solution of MOO problems has significantly increased due to their ability to find a set of good quality solutions, although with no guarantee of Pareto-optimality though involving an acceptable computational effort without imposing too exigent requirements to the mathematical models.

Despite the success of metaheuristics and the applicability of these algorithms to a diverse set of problems in several areas, it has been recognized that there is no algorithm considered as the best approach to solve all types of problems [1, 2]. Very often, researchers use hybrid metaheuristics since they combine advantageous characteristics of different approaches to develop more efficient and effective algorithms. The choice of metaheuristics to hybridize strongly depends on the nature of the problem to be dealt with.

The direct load control problem in electricity distribution networks deals with the design of on/off patterns to be applied to controllable loads to achieve economical, technical and quality of service benefits. Three algorithms have been developed and compared to tackle this problem: a hybrid multi-objective algorithm based on Greedy Randomized Adaptive Search Procedure (GRASP) and Simulated Annealing (SA) called GRASP+SA, an evolutionary algorithm (EA) with an embedded construction phase (EGRASP), and an EA with incorporation of preferences (EvABOR-III). Preferences are also incorporated in the hybrid metaheuristics (GRASP+SA and EGRASP) using an outranking relation to sort the non-dominated solutions in categories according to the preferences elicited from a decision maker (DM).

2 A brief description of the proposed algorithms

The multi-objective GRASP+SA approach is a hybrid algorithm consisting of three main phases: a construction phase based on the principles of GRASP, a local search phase using the SA algorithm, and the selection of individuals to the next iteration. In the construction phase, a set of feasible solutions is generated according to the characteristics of the problem and/or the preferences elicited from the DM. Due to the multi-objective nature of the problem, several restricted candidate lists (RCLs) are used, each one based on a different objective function or a specific characteristic of the problem. Whenever preferences are elicited from a DM, these are also used to sort the candidate elements in the RCLs. The construction phase is followed by a local search phase to exploit the neighborhood of each solution using a SA algorithm with incorporation of preferences. This exploitation is performed for each temperature value (as in classical SA). The temperature decrease implies that the probability to accept a solution for further exploration also decreases, as usual. An archive is used during the local search to save the solutions belonging to the best class. A set of neighborhood structures specifically designed for the problem is used to exploit the neighborhood of each solution in the archive. New solutions are classified into categories of merit based on the DM's preferences and this information is included in the probability acceptance function to decide about the exploitation of neighbor solutions. As the aim of this local search is to increase the convergence to a region more in accordance with the DM's preferences, it makes sense that the preference information is also used during the search process.

The construction phase used in the GRASP+SA algorithm is also used in an EA with incorporation of preferences (EGRASP). In this approach, the construction phase captures the main features of the problem to improve the quality of the solutions obtained. Preferences are also incorporated in EGRASP, both in the construction phase and in the genetic operators (mutation, crossover and selection of the next generation).

Finally, an evolutionary algorithm with incorporation of preferences (EvABOR-III) has been developed to provide solutions to the direct load control problem. More details about this algorithm can be found in [3]. Preferences are included in all algorithms using the ELECTRE TRI method [4], which permits to classify solutions in categories of merit.

3 A direct load control problem: results and conclusions

The direct load control problem is challenging due to its combinatorial nature and in our case study also due to the number of objective functions. In this case, the aim is to design and select load control strategies to optimize seven objective functions: minimize the maximum peak power demand in a sub-station (SS) and in two distribution power transformers (PT1 and PT2), maximize profits with the sale of electricity, minimize the total time in which loads are in curtailment, and minimize the maximum continuous time interval in which discomfort has occurred and the total time of this occurrence. The discomfort is assessed by a variable (usually associated with temperature) and increases whenever it is over or under a pre-specified threshold. In our problem 500 air conditioners (ACs) units, grouped in 24 groups are controlled, and load control actions are applied in the usual period ACs are in use. Details of this problem, including the mathematical model, can be found in [5].

The three approaches have been applied to provide decision support to this problem. Results have shown the benefits of the construction phase in GRASP+SA and EGRASP algorithms, in particular if the set of DM's preferences is more exigent. The use of several RCLs, reflecting the multi-objective nature of the problem, is another advantage of these two approaches in which a multi-objective GRASP is hybridized with other metaheuristics (SA and EA, respectively). The load control actions obtained with these hybridized approaches provide better results than the ones obtained with EvABOR-III minimizing simultaneously the maximum peak power demand in the SS, in the PT1 and in the PT2, reducing the total period of time in which loads are in curtailment without degrading discomfort and profits.

Acknowledgements

This work has been partially supported by the Portuguese Foundation for Science and Technology under project grant PEst-OE/ EEI/UI308/2014.

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