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PhD Thesis

OPTIMIZATION TECHNIQUES FOR COMMITTING COMBINED CYCLE POWER PLANTS AND DESIGNING THEIR COMPONENTS

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Abstract

This PhD thesis proposes and assesses new optimization methods and software based on evolutionary algorithms (EA), to deal with problems on the design and optimal commitment of combined cycle power plants (CCPP), which are based on the gas/steam turbines (GT/ST). The proposed methods are tested on indicative applications on the design and use of CCPP and their components. They are proved to exploit the advantages of EAs, such as handling of multi-disciplinary optimization problems, being independent of the analysis software, etc., and, also, considerably reduce their computational burden.

Applications related to the design of optimal CCPP and their components involve often a high number of design variables, constraints and objectives. To efficiently solve this kind of problems, a low-cost metamodel-assisted memetic algorithm (MAMA) is proposed. Metamodel-assisted EAs (MAEAs) are low-cost optimization algorithms for CPU demanding problems that make use of locally built metamodels for the inexact pre-evaluation of the offspring population. Memetic algorithms (MA) are hybrid methods that combine global and local search, aiming at improving the quality of promising solutions. The proposed MAMA combines and extends the capabilities of MAEAs and MAs. In MAMAs, metamodels undertake a dual role: they are used for the low-cost pre-evaluation of EA members during the global search and during the gradient-based refinement of promising solutions by approximating the gradient of the objective function. The dual use of metamodels reduces significantly the number of calls to the evaluation tool and overcomes the need for computing the exact objective function gradients. In multi-objective problems, during the refinement of promising individuals, a scalar strength function is maximized and this is proved to be beneficial in constrained optimization. Lamarckian learning is employed on the refined chromosomes. The use of the proposed MAMAs is demonstrated on engineering applications from the aforementioned application area.

The techno – economic design of CCPPs may also involve integer variables and different scenarios of candidate solutions, which differ in terms of the design variables and their number. As an example, the selection (a) of the optimal GT model from a list of models which are available in the marketplace and (b) of the optimal heat recovery steam generator configuration, involves integer variables, for the GT type and different chromosomes, for the HRSG type. To efficiently cope with these applications, a new distributed EA with semi-autonomous demes is proposed and used. Concerning the optimal commitment of power generating CCPP units (unit commitment, UC), a number of realistic aspects are dealt with: by considering both deterministic and stochastically varying power demand distributions in time and probabilistic unit outages. Apart from the minimization of the total operating cost for the known mean power demand distribution over the scheduling horizon, the minimization of risk of failing to meet possible stochastic demand variations is also sought. To considerably improve the efficiency of conventional EAs and take advantage of their capabilities in solving multi – objective problems, a two – level, multi – objective optimization scheme, 2LEA, based on EAs is proposed. On the low level, a coarsened problem is defined and solved aiming at exploring the decision space at low CPU cost and locate promising solutions. A coarsening strategy, based on a suitable grouping of time units, is proposed. On the high level, all promising solutions traced during the low level search are expanded and injected into the corresponding EA population for further refinement. The scheduling horizon is partitioned in sub periods which are solved interactively using semi – autonomous EAs, which employ penalties to the objective – function(s) for a smooth transition from/to the adjacent sub periods. Representative test problems are solved using the proposed 2LEA, which proves to noticeably increase EAs efficiency despite the need of iterating.

In case of probabilistic unit outages, the expected total operating cost is minimized. To compute the cost function value of each 2LEA candidate solution (UC schedule), a Monte Carlo simulation must be carried out. The latter involves the evaluation of some thousands of replicates, each one corresponding to a series of availability and unavailability scenarios for each unit and generated according to the units' outage and repair rates and the corresponding probabilities. 2LEA candidate solutions are corrected according to each replicate and evaluated in terms of the corresponding TOC. The expected TOC is the average of the TOCs of all Monte Carlo replicates. Therefore, the CPU cost per Monte Carlo based evaluation increases noticeably and so does the CPU cost of the 2LEA. To overcome this difficulty, a novel way to implement metamodels is proposed. The metamodels are not trained on previously evaluated UC schedules but on a few unit outage scenarios selected among the Monte Carlo replicates and, then, used to predict the expected TOC. Based on this low cost, approximate pre – evaluation, only a few promising schedules in each generation undergo the exact but costly Monte Carlo simulation. The proposed 2LEA with metamodels is demonstrated on two test problems and is proved to drastically reduce the CPU cost, compared to a conventional EAs based exclusively on Monte Carlo simulations.

Keywords: Design Optimization, Combined Cycle Power Plants, Unit Commitment, Economic Dispatch, Stochastic Demand Variations, Probabilistic Unit Outages, Evolutionary and Memetic Algorithms, Metamodels, Monte Carlo.