Optimization Methods and Algorithms for Solving Of Hydro-Thermal Scheduling Problems.

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Abstract: Different optimization methods have been applied to solve hydrothermal scheduling problems. This study reviews some of the common optimization methods and algorithms their strengths and weaknesses. The study found out that with time, old methods are improved upon and novel methods are developed to provide for more efficiency, faster convergence, robustness, and adaptability.

Keywords: Optimization, ALM, DE, FAPSO, EDDP, Hydrothermal

I. Introduction

Optimal scheduling of power plant generation is the determination of the generation for every generating unit such that the total system generation cost is minimum while satisfying the system constraints [1]. All hydro-systems are unique in their characteristics. Natural differences in water areas, difference between release elements, control constraints, non-uniform water flow, sudden alterations in the volume of water flow due to seasonal or natural constraints, occurrence of flood, drought and other natural phenomenon are among factors that affect hydro scheduling. The objective of the hydrothermal scheduling problem is to determine the water releases from each reservoir of the hydro system at each stage such that the operation cost is minimized along the planning period [1].

The importance of hydrothermal generation scheduling is well recognized. An efficient generation schedule not only reduces the production costs but also increases the system reliability and maximizes the energy capability of the reservoirs [2]. Therefore, many methods have been developed to solve this problem over the past decades. The major methods include variational calculus [3], maximum principle [4], functional analysis [5], dynamic programming [6,7,8], network flow and mixed-integer linear programming [9,10,11,12], nonlinear programming [13], progressive optimality algorithm [14,15], Lagrangian relaxation method [16-18], and modern heuristics algorithms such as artificial neuralnetworks [19], evolutionary algorithm [20-22], chaotic optimization [23], ant colony [24], Tabusearch [25], Expert Systems [26] and simulated annealing [27]. But these methods have one or another drawback such as dimensionality difficulties, large memory requirement or an inability to handle nonlinear characteristics, premature phenomena and trapping into local optimum, taking too much computation time [2].

II. Optimization Methods and Algorithms

Hydrothermal scheduling of a power system is concerned with thermal unit commitment and dispatch, and the hourly generation of hydro units [16]. Over two decades, techniques have been developed and results obtained by using the Lagrangian relaxation technique for generating near optimal solution [28,29,30,31]. According to Yan et al [16], Lagrangian relaxation technique decomposes the problem into the scheduling of individual thermal units and the scheduling of individual watersheds, the disadvantage is that the dual solution is generally infeasible [29]. A heuristic method was developed by Yan et al [16] to generate a good feasible solution based on dual results. After the feasible solution is obtained, a few more high level iterations are carried out to obtain additional feasible solutions and the best feasible solution is selected. The final feasible cost and the maximum dual function value are used to calculate the dual gap, a measure of the quality of the feasible schedule. This method did not incorporate pumped-storage unit and cpu time was about four to five minutes.

Extended differential dynamic programming (EDDP) and mixed coordination technique was employed by [8]. The problem was decomposed into a thermal subproblem and hydro subproblem. The thermal subproblem was solved analytically and the hydro subproblem was further decomposed into a set of smaller problems that can be solved in parallel. It was also used to handle unpredictable changes in natural flow.

Zhang et al [32] presented a bundle trust region method (BTRM) to update multipliers within the Lagrangian relaxation framework. Lagrangian multipliers are usually updated by the subgradient method [33,32] which suffers from slow convergence caused by the non-differentiable characteristics of dual functions [32]. The bundle-type methods have been used to update multipliers and are reported in [34,35]. Problem formulation in this case was not split into dual sub-problems but three, I thermal units, J hydro units and K-pumped-storage units with an objective to minimize the total generation cost subject to system-wide demand and reserved requirements, and individual unit constraints. A hierarchical structure of the algorithm is presented.
Mendes et al [36] inquired into an algorithm for dual variable updating, using concepts of trust region and subgradient algorithms in order to improve both dual optimality and plan feasibility. Comparing with a conventional subgradient algorithm the limitation of using the developed algorithm was: the need to have a small oscillation of the dual function in a neighborhood of the optimal point for the dual problem. The advantages of using the developed algorithm are: good adaptation of step sizes as opposed to trial and error tuning of the parameters in conventional subgradient algorithms.

More recently, a report in 2002 by Nurnberg and Romisch [37] presented a two-stage stochastic programming model for the short or mid-term cost-optimal electric power production planning considering the power generation in a hydro-thermal generation system under uncertainty in demand (or load) and prices for fuel and delivery contracts. The algorithmic approach consisted of a stochastic version of the classical Lagrangian relaxation idea [38], which is very popular in power optimization [39-44]. The corresponding coupling constraints contained random variables, hence stochastic multipliers were needed for the dualization, and the dual problem represents a nondifferentiable stochastic program. Subsequently, the approach was based on the same, but stochastic, ingredients as in the classical case: a solver for the nondifferentiable dual, subproblem solvers, and a Lagrangian heuristics. It turns out that, due to the availability of a state-of-the-art bundle method for solving the dual, efficient stochastic subproblem solvers based on a specific descent algorithm and stochastic dynamic programming, respectively, and a specific Lagrangian heuristics for determining a nearly optimal primal solution, this stochastic Lagrangian relaxation algorithm becomes efficient [37].

Gil et al [45] proposed a new model to deal with the short-term generation scheduling problem for hydrothermal systems using genetic algorithms (GAs), a metaheuristic technique inspired on genetics and evolution theories [46]. During the last decade, it has been successfully applied to diverse power systems problems: optimal design of control systems [47,48]; load forecasting [49]; OPF in systems with FACTS [50-52]; FACTS allocation [53]; networks expansion [54-56]; reactive power planning [57-59]; maintenance scheduling [60,61]; economic load dispatch [62,63]; generation scheduling and its subproblems [64-69]. The model handles simultaneously the subproblems of short-term hydrothermal coordination, unit commitment, and economic load dispatch. According to Gil [45] HGSP involves three main decision stages usually separated using a time hierarchical decomposition (Fig. 2): the hydrothermal coordination problem (HCP), the unit commitment problem (UCP), and the economic load dispatch problem (ELDP).

A scheme of the model as presented in Fig. 3, uses as input information, the FCF obtained from a long/mid-term model, detailed information on the hourly load demand, the reservoir inflows and water losses, models of the hydro and thermal generating units and initial conditions, among others. The model uses this input information, handling simultaneously the subproblems of short-term hydrothermal coordination, unit commitment, and economic load dispatch. Considering an analysis horizon period of a week, the model obtains hourly generation schedules for each of the hydro and thermal units [45].

![Figure 1 The Hierarchical Structure of the Algorithm][32]

![Figure 2 Time hierarchical decomposition for the HGSP][45].

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[45]: Figure 2 Time hierarchical decomposition for the HGSP [45].
Yuan et al [2] proposed a new enhanced cultural algorithm (ECA) to solve the short-term generation scheduling of hydrothermal systems. Cultural algorithm proposed by Reynolds in 1994 [70] is a technique that incorporates domain knowledge obtained during the evolutionary process so as to make the search process more efficient. CA is a technique that adds domain knowledge to evolutionary computation methods. It is based on the assumption that domain knowledge can be extracted during the evolutionary process by means of the evaluation of each point generated. This process of extraction and use of information has been shown to be effective in decreasing computational cost while approximating global optima in optimization problems[2]. It has been successfully applied to solve optimization problems [71]

The procedure of the proposed ECA[2] for solving the short term generation scheduling of hydrothermal systems is described as follows.

Step 1: Set ECA algorithm parameters and input hydrothermal systems data.

Step 2: Initialize individual solution of water discharge vector Q for each hydro plant over the scheduling period in population space. Each individual randomly generated is coded using real numbers within their bounds constraint.

Step 3: Calculate storage of the reservoirs over the scheduling period using current values of water discharge.

Step 4: Using water discharge and storage, determine power output of each hydro plant over the scheduling period.

Step 5: Calculate thermal power generation using load balance over the scheduling period, and then evaluate the objective function value (total cost of thermal generation).

Step 6: Evaluate constraint violations using current values of discharge, storage and thermal powers over the scheduling period.

Step 7: Initialize the situational knowledge in belief space. According to the initial water discharge individuals Q in population space, find the best individual and set as initial situational knowledge.

Step 8: Initialize the normative knowledge in belief space. Let \( l_i \) and \( u_i \) be set as the lower and upper bounds for the \( i \)th water discharge decision variable, respectively.

Step 9: For each individual in the population space, apply the mutation operator of differential evolution influenced by a randomly chosen situational knowledge and normative knowledge and generate new offspring individual.

Step 10: According to Steps 3–6, evaluate the offspring individual generated.

Step 11: Based on the constraint handling mechanisms, replace the individual with the offspring, if the offspring is better.
Step 12: Update situational knowledge in belief space with the accepted individuals.
Step 13: Update normative knowledge in belief space with the accepted individuals.
Step 14: Check the termination condition. If the maximum iteration number is reached, then obtain the optimal results and stop. Otherwise, go to step 9.

To validate the results obtained with the proposed ECA method, the same problem was solved using a genetic algorithm (GA) and differential evolution (DE). The problems were also solved using the augmented Lagrange method (ALM) and two phase neural network algorithm (TNN). Comparison of results showed that the proposed ECA method can find a lower thermal plant total cost and a faster computation time than the other methods, yields better results while satisfying various constraints. Convergence property of the ECA method is better than that of DE and GA for the solving short-term generation scheduling of hydrothermal systems. The main reason is that the ECA method has a belief space and it can utilize sufficiently the problem-based domain knowledge obtained during the evolutionary process to make the search process more efficient, while DE and GA are lacking this mechanism and thus make its search performance inferior to ECA [2].

Particle swarm optimization (PSO) is a computation technique [72] and has been successfully used in many areas [73-76]. Although PSO has many advantages it has some shortcomings such as premature convergence [77]. To overcome these problems, many methods have been developed, among them is the inertia weight method [78,79]. This could improve the algorithm but does not truly reflect the actual search process to find the optimum. Chang[77] proposed a fuzzy adaptive particle swarm optimization (FAPSO) to the operation of hydro-thermal power system designed to adjust the inertia weight as the environment changes. Fig 4 presents the flowchart of operations for the FAPSO. Chang [77] reports that FAPSO generates better solutions than other methods, mainly because it is implemented to dynamically adjust the inertia weight by using “IF-THEN” rules, this can improve the global and local search ability of the PSO and overcome the disadvantages of the PSO. Although almost all works which use dual decomposition in the Short-Term Scheduling (STS) problem are based on either Lagrangian Relaxation (LR) [42, 80-85] or Augmented Lagrangian (AL) [86–88], Rodrigues et all[89] proposed a two-phase approach similar to [90,91], but introduced contributions. In the first phase, LR was used to obtain (Infeasible) primal solution, and in the second phase the AL was used to obtain a solution whose quality can be assessed by the LR. Aiming to deal with nonlinearities and binary variables of hydrosystems, the LR was used but including the AL second-phase optimization in order to achieve primal feasibility, modeling all nonlinearities and binary variables related to hydro- and thermal units. The infeasibility between generation and demand is eliminated and the artificial constraints are satisfied.

Typically, LR technique relaxes coupling constraints such as demand and reserve requirements. Nevertheless, using this strategy, the hydro-subproblem remains coupled in time and space [89]. An alternative approach consists in combining LR with Variable Splitting-LRVS method [92,44], where the decomposition is achieved.

![Figure 4 The framework flow chart of FAPSO [77]](image-url)
by duplicating some variables. Rodrigues et al [89] used the LRVS to duplicate thermal and hydrovariables, as well as the turbine inflow and spillage variables, thus obtaining four subproblems: thermal, hydro, hydrothermal, and hydraulic. The first two subproblems take into account the unit commitment constraints (thermal and hydro). The hydrothermal subproblem considers demand reserve and transmission constraints. Finally, all the reservoir constraints are modelled into the hydraulic subproblem. Given that the LRVS fails to find a feasible solution, an AL approach was used in attempt to overcome this issue. The artificial constraints relaxed in the LRVS are taken into account in the AL function. In order to maintain the decomposition, the Auxiliary Problem Principle (APP) [93] was employed. In terms of solution strategy, the pseudo primal point strategy [94] was included as a warm starting by the APP. This strategy improves dramatically the performance of the APP algorithm.

III. Discussion

According to Atul [1], the operating cost of thermal plant is very high, though their capital cost is low. On the other hand, the operating cost of hydroelectric plant is low, though their capital cost is high, so it has become economical as well as convenient to have both thermal and hydro plants in the same grid. The objective of optimal operation to hydrothermal power is usually to minimize the thermal cost function while satisfying physical and operational constraints [77].

Intensive reviewing shows that hydrothermal generation scheduling problem has to be decomposed into smaller problems in order to solve it [95]. Since the Lagrangian relaxation (LR) approach was proposed in [96] for solving the problem of optimal short-term resource scheduling in large-scale power systems it has been recognized as a good approach [97, 85]. One of the most appealing properties of the LR approach is its linearity between the computing time and the number of resources, its convenience to handle resource-specific constraints and its estimation of the quality of the solution, that is, the duality gap. The LR approach can be interpreted as a two-stage hierarchical process, a decomposition stage and a coordination stage. The last stage consists in solving an optimization problem called dual problem, involving the updating of the dual variables [36]. One optimization techniques to solve the dual problem has been the usual subgradient algorithm. Its suffers from some drawbacks, the selection of the rule for the step size is one crucial problem [36] and suffers from slow convergence caused by the non-differentiable characteristics of dual functions [32]. The main advantages of the LR are as follows: the original problem can be split into a sequence of smaller easy-to-solve subproblems, and a lower bound for the optimal objective function is supplied. However, there is an important disadvantage: for nonconvex problems, the LR fails to find a feasible solution. On the other hand, with AL, it is possible to obtain a feasible solution or a near-feasible solution [89].

Convergence property of the ECA method is better than that of DE and GA for solving short-term generation scheduling of hydrothermal systems. The main reason is that the ECA method has a belief space and it can utilize sufficiently the problem-based domain knowledge obtained during the evolutionary process to make the search process more efficient, while DE and GA are lacking this mechanism and thus make its search performance inferior to ECA [2].

Based on this review, the fuzzy adaptive particle swarm optimization (FAPSO) [77] and the Lagrangian and Augmented Lagrangian [89] methods produced faster convergence and efficient optimization schemes.

IV. Conclusion

All the techniques reviewed and methods presented claim to have faster convergence time and reduced CPU speed. After intensive reviewing, it is unsurprising that, certainly new efficient methods are developed continually to increase computation speed and achieve near ideal convergence for optimal schedule of hydrothermal systems. In this review, the two most recent articles [77] and [89] are efficient models that attempted to consider all factors in the problems of scheduling hydrothermal systems. It is hoped that this paper exposes to its audience the studies carried out in optimization of hydrothermal systems.

References


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