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A Survey on Various Optimization Methods Applied for Solving Short-term Hydrothermal Coordination Problems

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ABSTRACT

Background: Short-term hydrothermal coordination (STHTC) is a very complicated optimization problem. It is a dynamic large-scale non-linear problem and requires solving unit commitment and economic power load dispatch problems. From this perspective, many successful and powerful optimization methods and algorithms have been employed to solve this problem. These optimization methodologies and techniques are widely diverse and have been the subject of ongoing enhancements over the years. **Objective:** This paper presents a survey of literature on the various optimization methods applied to solve the STHTC problem. A review and a methodology-based classification of some of the publications on the topic are presented. **Result**: Various optimization techniques that tackled the problem are overviewed and classified with their advantages and limitations having been critically discussed. **Conclusion:** This paper presents a bibliographical survey of the work published on the application of different optimization methods used to solve the short-term hydrothermal coordination problem.

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INTRODUCTION

In traditional power system Hydrothermal scheduling, the objective function is to minimize the operational cost of a hydrothermal system, while in restructured power systems, it is used for minimizing the operational cost or maximizing profit which is called hydro-thermal self scheduling (HTSS) in the case of profit maximization

In most power systems, there are three major types of generation - nuclear, thermal, and hydro. Nuclear generation is normally used to supply base load due to its high efficiency and slow response rate.

Thermal units are used for both base load and peak regulation depending upon their efficiency and response rate. Hydro generation units, due to their limited water resources and high response rates, are normally used to perform the system peak regulation. In a system with both hydro and thermal units, a well coordinated generation schedule can save power companies tremendous fuel costs.

In addition to achieving minimum production cost, a well coordinated hydrothermal generation schedule must also satisfy several constraints such as power balance at every time stage, available water resource limits and generation output limits. Many different methods have been developed to solve this problem. They are Lagrangian relaxation and Benders decomposition-based methods, Mixed-integer programming, Dynamic programming, Evolutionary computing methods, Artificial intelligence methods, Interior-point methods.

Optimization Methods for Short-Term Hydrothermal Coordination Problem:

A wide range of optimization techniques has been applied to solve the STHTC problem. These techniques are principally based on the criterion of local search through the feasible region of solution. Applied optimization methods can be mathematical programming algorithms such as linear and non-linear programming, dynamic programming and interior-point methods. Among the other methods are the artificial intelligence techniques including neural networks, fuzzy systems and the evolutionary methods such as genetic algorithms and the simulated annealing.

The methods considered in this survey can be classified as follows:

• Lagrangian relaxation and Benders decomposition-based methods

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• Mixed-integer programming
• Dynamic programming
• Evolutionary computing methods
• Interior-point methods

Lagrangian Relaxation and Benders Decomposition-Based Methods:

Lagrangian relaxation method offers a new approach for solving HTC problem for large-scale power systems (Al-Agtash, S., 2001; Ahmed, M.M.M., 2002; Ruzic, S., R. Rajakovic, 1998; Salam, M.S., 1997; Md. Sayeed Salam, 1998; Sinha, N., L. Lai, 2006; Šulek, P., 2012). The basic idea of Lagrangian relaxation method is to relax demand and reserve requirements using Lagrangian multipliers. The new problem, called the dual problem, can then be decomposed into the scheduling of individual thermal and hydro units. The multipliers are then adjusted iteratively to maximize the dual function. The relaxation of constraints causes a gap between the solutions of primal and dual problems called duality gap. Therefore, dual optimal solution rarely satisfies the power balance and reserve constraints. Hence it is necessary to search for a suboptimal feasible solution near the dual optimal point. The method of search is an iterative process that solves relaxed sub problems and updates Lagrangian multipliers according to the extent of violation of the power balance and the spinning reserve constraints.

Many HTC formulations used loss penalty factors in the solution algorithm for the dual problems but did not use variable loss in the primal problem. This leads to inconsistency in the solution approach (Cohen, A.I. and V.R. Sherkat, 1987) and widens the duality gap. On the other hand, problem which considers network losses fixed and lumped into load, will produce suboptimal solution compared to the problem using variable network losses.

In [30] paper, reporting a new approach denoted as hydrothermal scheduling based Lagrangian relaxation (HTSLR) approach. Nonlinear functions for thermal generation cost and water discharge characteristics are used. The HTS is used to solve for the output levels of hydro units. They used an efficient algorithm to solve the HTS problem (Abdul Halim, 1991). At the final stage, a refinement algorithm has been developed to fine-tune the schedule. The loss formulation in the dual problem is variable except for the cross-coupling terms between generating units. Exact variable loss equation is used in the primal problem. This allows the solution approach to be consistent and to obtain more accurate schedules.

Results of the implementation on a practical utility data show that the HTSLR approach produces better schedules than the SLR approach suggested in the literature (Aoki, A., 1987; Tong, S.K. and S.M. Shahidehpour, 1990; Yang, J.S., N. Chen, 1989). The results also demonstrate an improvement in system constraint violations. The improvements in the algorithm have contributed to this better performance (Md. Sayeed Salam 1998).

Extensive constraints i.e. power balance, spinning reserve; minimum up down time, capacity limits, ramp rate, and limited generation for the first and last hour and hydro constraints are incorporated. Transmission loss is incorporated using a general transmission loss formula. Nonlinear functions for thermal generation cost and water discharge rate are used. The proposed algorithm derived the dual function in the same manner as the SLR. The thermal subproblem is used to solve for the commitment status of thermal units. The implementation of the algorithm differs from the SLR in which commitment status is used by the HTS to solve for the unit output. The hydro output from the HTS can be used as the solution for the hydro subproblems (Md. Sayeed Salam 1998).

Mixed-Integer Programming:

In (Ahmadia, A., 2012) paper, presents a method for hydro-thermal self scheduling (HTSS) problem in a day-ahead joint energy and reserve market. The HTSS is modeled in the form of multi objective framework to simultaneously maximize GENCOs profit and minimize emissions of thermal units. In the proposed model the valve loading effects which is a nonlinear problem by itself is linearized. Also a dynamic ramp rate of thermal units is used instead of a fix rate leading to more realistic formulation of HTSS. Furthermore, the multi performance curves of hydro units is developed and prohibited operating zones (POZs) of thermal unit are considered in HTSS problem. Also, in the proposed framework, the mixed integer nonlinear programming (MINLP) of HTSS is converted to mixed integer programming (MIP) problem that can be effectively solved by optimization softwares even for real size power systems. The lexicographic optimization and hybrid augmented-weighted-constraint technique is implemented to generate Pareto optimal solutions.

In (Ahmadia, A., 2012) paper a realistic MIP model is presented for HTSS in which valve loading effects cost, dynamic ramp rate, POZs, fuel limitation are considered, all in linear model. It also includes multi performance curves for hydro units. The proposed method is efficiently solved by analytic method using lexicographic optimization and hybrid augmented-weighted-constraint technique. The best compromise solution among the Pareto optimal solution can be selected either by the fuzzy method or arbitrage opportunity approach. The computation burden of the proposed method is significantly decreased mainly for the linear formulation; making it a practical even for HTSS of real sized large scale power system, including hundreds of thermal and hydro units.

In (Šulek, P., 2012) proposes a new hybrid optimization method for solving a hydrothermal coordination problem. In general, the problem is

decomposed into smaller hydro and thermal sub-problems which are solved separately. The hydro sub-problem is solved by the peak shaving method using the proposed hybrid optimization method. It combines genetic algorithms with the traditional numerical optimization method. The hybrid method has been applied to a real hydrothermal system.

Dynamic Programming:

Among these various methods, dynamic programming is widely used to solve this problem. However, it requires long Computation time and large storage memory in practical systems. A new dynamic programming algorithm, the multi-pass dynamic programming that will reduce both the storage memory and computation time is proposed in this paper. It is combined with the successive approximation technique and applied to the hydrothermal coordination problem.

The dynamic programming optimization approach has been extensively used to solve the hydrothermal coordination problem because of the complexity of this problem and existence of the dynamic variables. The ability of dynamic programming to overcome the difficulty of the non-linearity and non-convexity of large-scale systems is another reason for its popularity. In dynamic programming techniques, large size problems, which consist of many state variables and dynamic elements, are decomposed into smaller problems that could be solved independently. What so called the "curse of dimensionality" (Momoh, J.A., 2001), which is the limited ability to solve large-sized problems with large number of variables, is the main disadvantage of dynamic programming. In spite of this drawback, it has been applied to various power system areas and studied by a considerable number of publications in the literature. Yang and Chen presented a special form of dynamic programming techniques in (Yu, S.N., 2006) to solve the STHTC problem. To improve the performance of dynamic programming and overcome its disadvantages, those are the high computational time and large memory storage, a multi-pass dynamic programming technique was implemented. The algorithm was tested using real data obtained from a realistic power system containing thermal and hydro units however, some constraints were not considered. Although the cases tested in this paper did convert to reasonable solutions, but there was no indication that global optimal solutions were guaranteed. In fact, the solutions that were reached might be local, especially when we keep in mind that the used algorithm was an iterative-based process.

In a multi-pass dynamic programming was integrated with an evolutionary programming algorithm in order to obtain an improved solution. Two case studies were presented to implement the approach considering, in addition to thermal and hydro units, pumped-storage units which either worked in pumping mode or generation mode with no idle times.

In (Jin-Shyr Yang, 1989) presents a very efficient new technique, the multi-pass dynamic programming (MPDP) combined with successive approximations, to solve the daily hydrothermal coordination problem. The long computation time and the large storage memory requirement are reduced. Furthermore, due to the characteristics of the hydrothermal coordination, the load following capability of this application of HPDP is much better than its application to area automatic generation control. The generation can now follow any shape of load curves instead of only constant loads and ramps as in the previous application.

Evolutionary Computing Methods:

Based on evolutionary theory and inspired by the principle of "survival of the fittest" (Fogel, D.B., 2003), evolutionary computation is one of the computational intelligence based approaches that have been applied to solve complex optimization problems (Miranda, V., 1998). Flexibility and capability to obtain good quality solutions are the advantages of evolutionary computation; however, these are highly affected by computer requirements and convergence characteristics. Several evolutionary computation techniques have been introduced and applied to powers system optimization problems, these include; genetic algorithms (GA), simulated annealing (SA), evolutionary strategies, evolutionary programming and particle swarm optimization (PSO).

This paper is dealing with the solution of the hydrothermal scheduling problem by using evolutionary algorithm. The aim of this study is to minimize the fuel cost and ramping cost of thermal units by utilizing both hydro and thermal units optimally. In evolutionary programming, new generations are produced from randomly generated initial vector by Gauss and Cauchy mutations and they compete with parent vectors and each other. Better individuals are selected for the next generation. The new generation process lasts until either reach to defined iteration number or a minimum function value or the point where developed solutions are no longer different**.**

Genetic Algorithm:

Genetic algorithms have been widely applied to power systems since they were introduced by John Holland in his book (Hollan, J.H., 1975) in 1975. GA is a search technique that searches for a population of solution points starting from an initial arbitrary solution within the feasible region (Momoh, J.A., 1995). Genetic algorithms have become one of the most popular approaches because of the many advantages that have been acknowledged such as their ability to handle any objective function with any constraints. Moreover, they are less likely to

converge to local minima since their population-based search is a probabilistic transition strategy. On the other hand, their main weakness is the high computational time required for convergence (Bansal, R.C., 2005). Various power system planning and operation problems have been solved using genetic algorithms such as economic dispatching, unit commitment and hydrothermal coordination problems. One of the earliest applications of GA to solve the STHTC problem was presented in (Chen, P., H. Chang, 1996).

A new model to deal with the short-term generation scheduling problem for hydrothermal systems is proposed (Esteban Gil, 2003). Using genetic algorithms (GAs), the model handles simultaneously the sub problems of short-term hydrothermal coordination, unit commitment, and economic load dispatch. Considering a scheduling horizon period of a week, hourly generation schedules are obtained for each of both hydro and thermal units. Future cost curves of hydro generation, obtained from long and mid-term models, have been used to optimize the amount of hydro energy to be used during the week. In the genetic algorithm (GA) implementation, a new technique to represent candidate solutions is introduced, and a set of expert operators has been incorporated to improve the behavior of the algorithm. Results for a real system are presented and discussed.

In (Christoforos E. Zoumas, 2004), three problems traditionally analyzed separately: short-term HCP, UCP, and ELDP. Hydrothermal systems are coupled in time. In order to uncouple the long/mid-term models from the short-term model, FCFs have been used. In this way, FCFs work as the link between the short and the mid/long-term models. The definition of the decision variables, the representation of candidate solutions, and the fitness evaluation are the basis for implementing a GA. They act like the connection between the electric/economic model and the GA. Once these aspects are solved, the solution through GAs is fundamentally a programming problem.

Particle Swarm Optimization (PSO):

Particle swarm optimization (PSO) is an evolutionary method motivated by the social behavior of bird flocks and fish schools. PSO was first introduced in 1995 by Kennedy and Eberhart (1995) as a heuristic algorithm for non-linear optimization problems. In addition to the advantages of other evolutionary methods such as simplicity and ability to handle complex objective functions, PSO algorithm does not include many parameters to adjust and does not need perfect initial points. On the other hand, PSO is not ideal from a mathematical background viewpoint and it cannot guarantee convergence to global solutions (AlRashidi, M.R.,). PSO algorithms have been widely applied to various complex optimization problems including power system operational planning and design problems. A comprehensive survey of PSO applications in various areas of power system optimization as well as a review of the advantages and disadvantages of this approach were presented in (AlRashidi, M.R.,).

In (Sinha, N., L. Lai, 2006), PSO application for short-term hydrothermal scheduling problem was studied and compared to other meta-heuristic search algorithms. Comparison revealed that PSO approach was superior as it proved better convergence characteristics and less solution time.

The practical hydrothermal system is highly complex and possesses nonlinear relationship of the problem variables, cascading nature of hydraulic network, water transport delay and scheduling time linkage that make the problem of finding global optimum difficult using standard optimization methods. In (Hota P.K., 2009) paper an improved PSO technique is suggested that deals with an inequality constraint treatment mechanism called as dynamic search-space squeezing strategy to accelerate the optimization process and simultaneously, the inherent basics of conventional PSO algorithm is preserved. To show its efficiency and robustness, the proposed IPSO is applied on a multi-reservoir cascaded hydro-electric system having prohibited operating zones and a thermal unit with valve point loading. Numerical results are compared with those obtained by dynamic programming (DP), nonlinear programming (NLP), evolutionary programming (EP) and differential evolution (DE) approaches. The simulation results reveal that the proposed IPSO appears to be the best in terms of convergence speed, solution time and minimum cost when compared with established methods like EP and DE.

In (Chandrasekar Samudi,), a new approach of particle swarm optimization (PSO) algorithm for short term Hydro Thermal Scheduling (HTS) problems. Various possible particle selections have been studied and its effects on the global optima have been discussed. The effectiveness and stochastic nature of proposed algorithm has been tested with standard test case and the results have been compared with earlier works. This paper also describes software developed for short term hydro-thermal scheduling by considering hydro economic dispatch and thermal unit commitment. The proposed algorithm is ideally suitable for hydro-thermal co-ordination problems, hydro economic dispatch problems with unit commitment, thermal economic dispatch with unit commitment problems and scheduling of hydraulically coupled plants.

The fundamental requirement of power system hydrothermal scheduling is to determine the optimal amount of generated powers for the hydro and thermal units of the system in the scheduling horizon of 1 day or few days while satisfying the constraints of the hydroelectric system, thermal plants and electrical power system (Nima Amjady, 2009). Daily

Hydrothermal Generation Scheduling (DHGS) is a complicated non-linear, non-convex and non-smooth optimization problem with discontinuous solution space. To deal with this complicated problem, a new Modified Adaptive Particle Swarm Optimization (MAPSO) is proposed in this paper. The inertia weight and acceleration coefficients of the PSO are adaptively changed in the MAPSO owning tree topology. We split-up the cognitive behavior of PSO into the best and not-best parts. The proposed not-best cognitive component, unlike recent methods, retains its dynamic behavior throughout the search process. Personal best position exchanging method is proposed to increase activities of particles to explore broad space. New velocity limiter is also proposed in this paper to enhance exploration capability and convergence behavior of the MAPSO. The proposed MAPSO is tested on six test systems and compared with some recent research works in the area.

Interior Point Method:

In a clipping-off interior point algorithm for hydro-thermal coordination which allocates hydro and thermal resources in order to minimize the cost is given. The clipping-off algorithm basically consists on setting as the control variables to their upper or lower bounds if certain conditions are met, and eliminating them variables from the problem formulation thereafter. The number of flops and iterations to obtain the problem solution is considerably reduced as compared to a standard interior-point solution; however, the solution obtained by either method is the same. Based on the hydro- thermal power system of Spain, computational examples are presented; these examples are used to compare the proposed clipping-off predictor corrector log barrier algorithm with the standard predictor-corrector and the standard log-barrier algorithms.

In (JosC Medina 1998), the performance of newly developed and currently under development interior-point optimization codes as applied to the solution of medium-term hydro-thermal coordination (MTHTC) problems. We compare commercial and research codes, and their main advantages and drawbacks are pointed out. The main features of four very recently developed research algorithms and CPLEX log barrier code are discussed. Their performance in finding a solution to the hydro-thermal coordination problem is compared *to* the performance of simplex-based methods. The solution to a realistic medium-term hydro-thermal coordination problem that is based on the mainland Spain power system is briefly presented. The results show that interior-point methods can solve large hydro-thermal coordination problems faster than simplex decomposition-based methods.

Conclusion:

This paper presents a bibliographical survey of the work published on the application of different optimization methods used to solve the short-term hydrothermal coordination problem. Various optimization techniques that tackled the problem are overviewed and classified with their advantages and limitations having been critically discussed. The paper provides a general literature survey and a list of published references on the topic aiming to offer the essential guidelines regarding this active research area.

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