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SHORT TERM HYDRO THERMAL SCHEDULING PROBLEM: A REVIEW

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Abstract: Operation of a system having both hydro and thermal plants is far more complex and is of much more importance in a modern interconnected power system. The objective of the STHS problem is to optimize the electricity production, considering a short-term planning horizon. This paper presents an extensive review of a short term hydro thermal scheduling problem. The paper demonstrates results of various evolutionary and analytical methods applied on a short term hydro thermal scheduling problem .All the assumptions made and a brief description of the solution methods is presented in the paper. The paper provides helpful information and resources for the future studies for researchers those interested in the problem or intending to do additional research in this area.

Key words: *short term hydro thermal scheduling, optimal scheduling, evolutionary and analytical approaches*

1. INTRODUCTION

Today's modern power system consists of a large number of thermal and hydro plants connected at various load centers through a transmission network. The main objective of operation for such a power system is to generate and transmit power to meet the system load demand and losses at minimum fuel cost. The study of the problem for optimum scheduling of power generation at various plants in a power system is of paramount importance, particularly where the hydro sources are scares and high cost of thermal generation has to be relied upon to meet the power demand and losses. The short-term hydrothermal scheduling is of great importance to electric utility system, which involves the hour by- hour scheduling of all generations in system in order to achieve minimum the fuel cost for a known scheduling horizon. The scheduling objective is to plan the usage of water available for hydroelectric generators in order to reduce the production cost of the thermal plants with a set of starting conditions such as reservoir volume.

Basically the integrated operation of the hydro-thermal system is split into two separate, long-range and short-range problems. The planning period is of one year for long-range problem and short-term hydrothermal scheduling problem is concerned with optimization over a time horizon of an hour, a day or a week. The paper focuses on a short term hydro thermal scheduling problem. Some authors have given an analytical approach while other has followed the evolutionary methods.

Several analytical and evolutionary methods given by various researchers are reviewed. The genetic algorithm, simulated annealing, evolutionary programming fuzzy system, particle swarm optimization, bacterial foraging algorithm, ant colony,

Fuzzy system, mixed integer programming and lagrangian method have come to be the most widely used tools for solving a short term hydro thermal scheduling problem.

The proposed work aim to present the overview and key issues of previously considered methods for short term hydro thermal scheduling problem. No attempt is made here to prove the effectiveness of the solution technique applied by researchers for hydro thermal scheduling problem.

2. REVIEW OF LITRATURE

Short term scheduling power system is a subject that has been extensively studied because of its significant economic impact. Hydro thermal scheduling is required in order to find the optimum allocation of hydro energy so that the annual operating cost of a mixed hydro thermal system is minimized. Over the last decade the hydrothermal scheduling problem has been the subject of considerable discussion in the power literature. The available methods differ in the system modeling assumptions and the solution method.

In June 1980 S. Soares, C. Lyra, and H.Tavares [1] applied decomposition and coordination technique for solving HTSP. The formulations used in this paper also take care of stochastic load demand. Demand. The method has been applied to a hydro thermal system consisting of 4 hydro and two thermal plants over a period with 12 stages. The method purposed by the author has desirable feature of matching a precise formulation of the problem with the ability to deal large scale coupled power system. The authors believe that improvement in computation time can be achieved with better individual value for Lagrange multiplier and amelioration in programming.

In February 1986 H. Habibollahzadeh, and J. A. Bbubenko [2] give decomposition technique for solving HTSP. Author developed a realistic model for short term operation planning for large scale hydro thermal power system. Benders' method is employed

to decompose the problem with respect to integer and continuous variables.The master problem of this method contains only integer variables and considers the unit commitment of thermal plants. The sub problem includes only continuous variables and considers the economic dispatch problem. The benders method used by author has slightly higher efficiency than the lagrangian relaxation method. The method is applied on Swedish power system consisting of 30 hydro and 20 thermal plants. The total time taken for computation is 4 minutes.

In August 1991 R.N Wu, T.H Lee and E.F Hill [3] proposed a duality decomposition method which was based on basic interchange scheduling strategy. The study shows that with the proposed method up to 1.6 % of saving were achieved and 2.9 % extra hydro energy yield. When the interchange averaged for 8 hours' time block the purposed method generates 2.2 % more of hydro energy and overall production cost reduced to 1.1 %. The computational time of algorithm is appealing and method is suitable for practical use. The system taken for the study purpose consists of three interchange contracts, five hydraulic cascaded hydro plants and seventeen thermal units

In January 1994 K.P. Wong and Y.W.Wong [4] gave a Simulated Annealing method for solving HTSP. The author has included the reservoir volume constraints and the operation limits of the thermal and hydro units in the algorithm. The employment of the random and Gaussian perturbation techniques in the candidate solution generation process, as well as the constraint relaxation method, enhances the performance of the algorithm. The algorithm developed has been implemented using the ***C*** programming language and the software system **is** run on a PC/486 computer with an i860 co-processor. The test example shows that the algorithm has good performance and it has the ability to determine the global optimum solution. The computation speed of the new algorithm can be improved by further developing the algorithm to exploit parallelism.

In January 1995 S. soares and T. Ohishi [5]performed case study via hybrid simulation-optimization approach. The author simulated the hydraulic system on the hourly basis, showing the water release from the hydro reservoirs. The release decision is totally based on the DC power flow. The reservoir release targets are enforced through a duality penalty approach which shadow costs to the hydro generation. The author used special nonlinear capacitated network with linear side constraints. Hybrid approach is applied to the 440kv companhia energetica do estado de sao in Southeast Interconnected Brazilian Power System. The system comprises of 15 buses and 21 branches, four hydro electric plants with three in the same cascade, and 11 load buses. The code has been implemented using Fortran 77 in a SUN sparc station IPX. The average time for script 2, starting with h = 0, is 20 sec. considering this initialization and a load variation of *5%,* the average CPU time is reduced to 7s. The tests showed the influence of specific constraints such as reservoir storage limits, and Limits on discharge variation.

In 1995 another research was done by O. Nilson and D. Sjelvgren [6] proposing a mixed integer programming method for solving the problem. The author decomposed the problem in to several sub problems and some coupling constraints were relaxed. In order to get smooth result the method includes startup cost for hydro aggregates. The main mathematical techniques applied in the problem were Lagrange relaxation, dynamic programming and network programming. Author applied the technique on Swedish power system. The duality gap came out to be less than 1 for 25 iteration and computation time was about 5-7 minutes for 25 iterations on a Macintosh Quadra 700. The main advantage of the method is that it only looks for points having better efficiency, thus reducing the computational time and quality of results

In march 1996 Md. S. Salam, K.M nor, and A. R. Hhamdan [7] give a comprehensive algorithm for solving HTSP. In this approach Lagrangian relaxation based hydrothermal co-ordination algorithm is integrated into an expert system. Author decomposed the scheduling problem to scheduling of individual unit by relaxing demand and reserve requirements using lagrangian multipliers. Dynamic programming has been used for solving thermal sub problems without discretising generation levels. The program is written in C language and expert system was developed in SICStus prolog. Programs were run on a SUN SPARC station 10 a practically tested on system using the data of the generating units and system demands of 1989 and 1993. The 1989 test system consisted of 32 thermal and **12** hydro generating units and 1993 system had 36 thermal generating units, of which 11 were gas turbine units and 12 hydro units. The results show that proposed approach produces feasible within a reasonable time.

In October 1998 Keun Yu, C **S** Chou, and Y H Song, [8] applied the ant colony search algorithm for solving the problem. In paper Ant Colony Search Algorithm, a set of co-operating agents called ants cooperate to find good solution to short-term Generation scheduling problem of thermal units. The effectiveness of the proposed scheme has been demonstrated on the daily scheduling problem of a model power system and the results are compared with the outcomes obtained by a conventional, hybrid DP type of scheduling method. The study results indicate that, in terms of economy, the proposed ACSAis applicable to the short-term generation scheduling problem.

In 15 February 1999 P.K Hota, R.Chakarbatai, P.K Chattopadhayay [9] gave an evolutionary programming technique for solving hydro thermal scheduling problem. Author has represented the thermal generator units by an equivalent unit and the

generator load power balance equations and total water discharge equation have been subsumed into the system model. The algorithm has been applied toa hydro plant an equivalent thermal unit and the schedule horizon is of 3 days and there are six 12-h intervals. The results demonstrate that the EP technique provides a cheaper schedule when compared with the SA and gradient search techniques and is more reliable and powerful in searching for the global optimal solution even than the SA algorithm

In November 2000 Yong-Gang Wu, Chun-Ying Ho,and Ding-Yi Wang [10] proposed a Diploid Genetic approach for solving HTSP. The proposed genetic algorithm uses a pair of binary strings with the same length to represent a solution to the problem. Crossover operator is carried out by means of separating and recombining technique, which is of the same effect of that of uniform crossover. Dominance mechanism in the algorithm's realized by a simple Boolean algebra calculation. Author implemented the algorithm in C language on a Pentium 166 personal computer. The system consists of 5 thermal plants and 4 variable head hydro plants. We used an 8-digit binary string to encode the generation of each plant in each interval. Pc and Pm are taken as 0.85 and .003 respectively with a population size of 60. The proposed algorithm obtains the same results as in 5000 generations of simple algorithm. The paper shows that diploid genotype structure along with the dominance mechanism shows a stronger ability to maintain the gene diversity in a limited population.

In March 2001 Ernan Ni, Peter B. Luh, and Xiaohong [11] Guan gave an Aggregation Method for Improving Lagrangian Relaxation-Based Auction Implementation and Generation Scheduling. In the paper author has removed deficiency of Lagrangian relaxationmethod. In this paper, an aggregation Method is developed to reduce the oscillation of sub problem solutions in the primal space and to improve the convergence of the dual Problem. For convex hydro sub problems, aggregation is performed as a convex combination of sub problem solutions across Iteration. The multipliers are updated at the high level based on high level based on the aggregate solution after solving a portion of sub problems rather than solving all the sub problems. The algorithm has been implemented in C++ on a Pentium 11-400 PC, and extensive numerical testing has been performed.Convergence of the aggregation method is proved in the paper.

In January 2003 M. Basu [12] purposed an interactive fuzzy satisfying method based on evolutionaryProgramming technique for solving an HTSP. The problem is formulated considering two objectives: (i) cost and (ii) emission. The majorAdvantages of this method lie in having a mechanism to show the vague or fuzzy preference of the human DM in obtaining a compromising solution in presence of conflicting objectives and capable of handling non smooth fuel cost and emission level functions. The method also allows the DM to decide on different preferences for the objectives according. The proposed method has been applied to a test System which consists of a multi-chain cascade of four hydro unitsand three thermal units. The scheduling period is 24 h with one hour time intervals and the average CPU time using Pentium 3 PC was 1 h, 16 min and 22 s.

In February 2003 Nidul Sinha, R. Chakrabarti, and P. K. Chattopadhyay [13] gave Fast Evolutionary Programming Technique for solving HTSP. Evolutionary programs with Gaussian mutation (CEP), Cauchy mutation (FEP), and better of Gaussian and Cauchy mutations (IFEP) were developed and demonstrated to solve the hydrothermal scheduling problem with quadratic thermal cost function together with and without valve point loading effect and with and without considering prohibited hydrodischarge zones. The algorithm is applied on an equivalent thermal and a multichannel cascade of four hydro units. The schedule horizon is 24 h with 1-h intervals. The programs were implemented in Matlab command line on a PC (Pentium-III, 128 MB, 850 MHz). Results show that with quadratic thermal cost and without prohibited discharge zones, all EP-based algorithms converge faster during initial stages while FEP and CEP slowdown in the latter stages compared to IFEP.

In October 2003 S.K. Bath, J.S. Dhillon, and D.P. Kothari [14] gave a Fuzzy satisfying stochastic multi-objective generation scheduling by weightage pattern search methods for solving scheduling problem. The paper mainly focuses on four objectives viz. operating cost, NO*x* emission and risk due to variance of active and of reactive power generation mismatch are simultaneously to be minimized. The author gave Specific technique is put forth to convert the stochastic models into their respective deterministicequivalents. The weighting method is used to simulate the trade-off relationship between the conflicting objectives in the non-inferior domain. The validity of proposed method has been demonstrated on an 11-node IEEE system having five generators. The results obtained by searching weightage pattern using Hooke–Jeeves and evolutionary search techniques.

In November 2003 another approach based on Genetic algorithm was given by Esteban Gil, Julian Bustos, and Hugh Rudnick [15]. The author decomposed the HTSP in to three different smaller problems: hydrothermal coordination problem (HCP), then unit commitment problem (UCP), and the economic load dispatch problem (ELDP). Each problem is solved step by step respectively. The algorithm was programmed using MATLAB 5.3, and the simulations were performed using a 1-GHz Athlon processor. For tuning the GA parameter author first implemented it on pure thermal system

then on hydro thermal system. The results shows that proposed GA, using new specialized operators, have demonstrated excellent performance in dealing with this kind of problem, obtaining near-optimal solutions in reasonable times and without sacrificing the realism of the electric and economic models.

In august 2006 Nidul Sinhaand Loi-Lei Lai [16] give Meta Heuristic Search Algorithms for solving HTSP.Meta-heuristicis a higher-level general strategy which guides other heuristics to search for feasible solutions in domains where the task is hard. Meta heuristic search algorithms GAF, CEP, FEP, IFEP and PSO are developed and were demonstrated in solving the hydrothermal scheduling problem. The author concluded that PSO and all EP-based algorithms are more capable of finding highly near-global solutions than GA, SA and the gradient search methods. Results have exhibited that PSO has the fastest convergence rate to the global solution amongst all the algorithms. In addition, the performance of both PSO and IFEP are least affected by different initial trial solutions. Though PSO has the same success rate as IFEP, the convergence rate of PSO is much faster than IFEP. Hence, PSO has the highest potential of finding more nearly global solutions to hydrothermal scheduling problems.

In the year 2008 Chandrasekar Samudi, Gautham P. Das, Piyush C. Ojha, Sreeni.T.S, and Sushil Cherian [17] used particle swam optimization for HTSP solution. In the paper various possible particle selections have been studied and its effects on the global optima have been discussed. In the proposed algorithm, selection of the reservoir volume as the particle position searches the entire range ofsearch region and finds the global optimum solution. Author concluded that the proposed algorithm is more successful in reducing the cost searching the entire search space than all other earlier methods. Paper revels that algorithm has 100% success rate and finding the most nearest global solution in all 300 tests that was conducted. Software for real time hydro thermal scheduling applications has been developed using the proposed algorithm.

In April 2009 Kang Yong-hui , Zhang Zhigang, and Huang Weijun [18] purposed a NSGA-II Algorithms for Multi-objective HTSP. Fast Non-dominated Sorting Genetic Algorithm (NSGA-II), a new multi-objective genetic algorithm, is applied to the optimal scheduling model for the first time. The proposed method has been applied to a test system which consists of a multi-chain cascade of four hydro units and three thermal units. The scheduling period is 24h with one hour time intervals. The simulation results show that this proposal model increases generation benefits of hydropower units, reduces operating costs of thermal units, advances comprehensive benefits of power systems, and provides a novel research thought for hydrothermal power systems short-term Optimal scheduling problems.

In 2010 September Fabrício Y. K. Takigawa, Erlon C. Finardi, Edson L. da Silva [19] gave a lagrangian relaxation method. In the paper A Lagrangian Relaxation – LR scheme based on a variable splitting technique is proposed.The purpose of this study is to analyze the decomposition strategy and the quality of the solution produced by the LR and the pseudo-primal point, which is calculated by active cuts of the Bundle method. Tests were performed on an Intel Core 2 Duo 2.33 GHz, 2 Gbytes of RAM with Windows XP Professional operational system. The programming language used was FORTRAN, using Compaq Visual FORTRAN Professional Edition 6.1.0 as a compiler. The used hydrothermal configuration has seven hydro and four thermal plants located in two subsystems. The proposed solution strategy makes possible the inclusion of new constraints in different sub problems, without modifying the solution structure.

In 2010 Fan-nie Kong, and Jie-kang Wu [20] cultural algorithm. The cultural algorithm combined with a novel equality constraint handing mechanism provides better solution at a lesser computational effort. CA based hydrothermal scheduling algorithm is implemented using Matlab code on a PIV 3.0GHz personal computer and is evaluated a test system which consists of a multi-chain cascade of four hydro units and three thermal units. Numerical results show that highly near-optimal solutions can be obtained by CA method compared with the improved particle swarm Optimization. Paper concludes that CA approach is able to provide better solution in term of fuel cost and computational effort..

In 2010Chengfu Sun, Songfeng Lu [21] Improved Quantum PSO.In the paper, quantum-behaved particle swarm optimization is improved employing heuristic strategies in order to handle the equality constraints especially water dynamic balance constraints and active power balance constraints. A feasibility- based selection technique is also devised to handle the reservoir storage volumes constraints. The improved heuristic strategies can be simply incorporated into QPSO method. Hence the proposed method does not require the use of penalty functions and explores the optimum solution at a relatively lesser computational effort. The proposed method can well be extended for solving the large-scale hydrothermal scheduling.

In April 2011 I. A. Farhat, and M. E. El-Hawary [22] gave a BFA to minimizing the cost function, the paper focuses on minimization of nitrogen oxides (*NOx*) also. The proposed algorithm is a modified bacterial foraging technique which applies a dynamic deceasing function for updating the solution vector and improving the convergence characteristics of the algorithm. The IBFA is applied to find the optimal scheduling of a hydro-thermal generation system of two thermal and two hydro plants considering the

minimization of the *NOx*Emission. The algorithm was implemented in MATLAB 7.8 and executed on an Intel Core 2 Duo 1.66 GHz personal computer. Simulation results have shown the effectiveness of the algorithm in finding theOptimum or near optimum solutions and capturing the cost emission trade-off relationship.

July 2011R.K. Swain , A.K. Barisal , and P.K. Hota , R. Chakrabarti [23] clonal selection algorithm, CSA, a new algorithm from the family of evolutionary computation, is simple, fast and a robust optimization tool for real complex hydrothermal scheduling problems. In this paper the proposed clonal selection algorithm based short-term hydrothermal scheduling algorithm is implemented in MATLAB 7.0, Pentium IV, 3.06GHZ with 256 RAM PC. The performance of the proposed CS algorithm is verified on three test systems. The CSA technique has been devised to efficiently handle the final reservoir storage limit. For all the cases, simulation results show that CSA based algorithm is capable of finding highly near-global solutions with lesser computational time than other established methods. In future, efforts will be made to incorporate the wind energy into the hydrothermal system using the proposed algorithm.

In July 2011 another author S.Padmini, C.Christober Asir Rajan [24] gave an improved PSO method. The appropriate values of population size NP and maximum iteration number Nmax are set to the values of 30 and 100. The entire optimization period is three days and it has been divided into 6 intervals and each interval is of 12 hours the results shows that best optimal solutions can be obtained by particle swarm optimization method, when compared with already existing techniques. Author concluded that The PSO technique can generate high-quality solution within shorter calculation time and more stable convergence characteristic than other stochastic methods.

3. CONCLUSION

In this paper, an overview and key issues of different research studies for short term hydro thermal scheduling is presented. Approaches based on different algorithms has been proposed and demonstrated to solve the short term hydrothermal scheduling problem. The effectiveness of the developed methods was tested on different systems and the results were also compared with other methods. It was observed that by tuning the control parameters of algorithms wisely the quality of result's can be improved. The provided information in the paper can be helpful researchers can lead to additional studies in the field, thus maximizing the effectiveness of scheduling algorithm and profit.

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