The Nucleus **50**, No. 1 (2013) 13-19

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

REVIEW ON THE IMPLEMENTATION OF PARTICLE SWARM OPTIMIZATION TECHNIQUE IN SOLVING THE HYDROTHERMAL SCHEDULING

S. ZAHEER, *S. HAROON, T.N. MALIK and I. HASHMI

Department of Electrical Engineering, University of Engineering and Technology, Taxila. Pakistan

(Received February 21, 2013 and accepted in revised form March 13, 2013)

Short term hydrothermal scheduling (STHTS) is a very complex, dynamic large-scale non-linear optimization problem. There are many algorithms and powerful optimization methods used to address this issue. Evolutionary algorithms have been effectively employed to obtain a global optimized solution of non linear problems like STHTS. Particle Swarm Optimization (PSO) is an evolutionary method. It can be successfully employed to get a best possible solution of STHTS problem due to its features of robustness, easy implementation and computational efficiency. Here the literature on the Particle Swarm Optimization method is collected and reviewed to sort out the STHTS problem. A review of most of the publications upto 2012 on this topic is given.

Keywords : Particle Swarm Optimization, PSO, Hydrothermal scheduling

1. Introduction

The combined operation of the hydro and thermal power systems is important for the best utilization of the energy resources. The economic aspects of such an operation cannot be left aside. The time base scheduling of hydrothermal systems aims to lessen the cost of operation of thermal plants and also looking after the different constraints of the power system networks. Short-term coordination between hydrothermal systems determines the best use of hydro and thermal resources for a short period of a single day or a week [1,2]. The problem can be mathematically represented by the following equation [1]:

$$\min C_T = \sum_{\tau=1}^{T} \sum_{k=1}^{M} C_k(P_T(k,\tau)) \quad (1)$$

C_T is the function of total cost, $P_T(k, \tau)$ is the power of a thermal unit k at time interval τ, $C_k(P_T(k, \tau))$ is the cost of production, M is the number of thermal plants and T is the number of time intervals.

The thermal power cost function can be written as:

$$C_k(P_T(k,\tau)) = a_k + b_k P_T(k,\tau) + c_k P_T^2(k,\tau) + \left| d_k.\sin(e_k.(P_T^{min} - P_T)) \right| \quad (2)$$

The objective function must fulfill different constraints which include [3] :

1.1 Load Balance

$$\sum_{m=1}^{N} P_H(m,\tau) + \sum_{k=1}^{M} P_T(k,\tau) = P_D(\tau) - P_L(\tau) = 0 \quad (3)$$

N is the number of hydro plants, $P_H(m, \tau)$ the power of hydro plant m at time interval τ, $P_D(\tau)$ is the load demand at time interval τ, $P_L(\tau)$ are net losses of the system at time interval τ.

1.2. Capacity of Hydrothermal Generation

$$P_T(k)^{min} \leq P_T(k, \tau) \leq P_T(k)^{max} \quad (4)$$

$$P_H(m)^{min} \leq P_H(m, \tau) \leq P_H(m)^{max} \quad (5)$$

$P_T(k)^{min}$ and $P_T(k)^{max}$ are the minimum and maximum power thermal plant k, $P_H(m)^{min}$ and $P_H(m)^{max}$ are the minimum and maximum power for hydro plant m respectively.

1.3. Total Water Discharge

$$\psi tot(m) = \sum_{\tau=1}^{T} \psi(m,\tau) \quad (6)$$

ψ(m, τ) is the rate of water discharge of the hydro plant m at time interval τ.

1.4. Hydraulic Continuity Equation

$$\upsilon(m, \tau) = \upsilon(m, \tau - 1) + [\psi(m, \tau) \; \sigma(m, \tau) - \varsigma(m, t)]l \quad (7)$$

υ(m, τ) is reservoir volume, ψ(m, τ) the rate of water discharge, σ(m, τ) the inflow rate, ς(m, τ) is the spillage discharge and l is the length of time interval τ.

* Corresponding author : saaqib.haroon@uettaxila.edu.pk

To address the problems of power systems [2] and power system optimization [4, 5] many methods were proposed and applied during different times. With the passage of time due to the development of new improved mathematical and other computational techniques not only different but some new problems arising in the system have been handled more qualitatively and efficiently.

2. Optimization Methods for Hydrothermal Scheduling

There are many optimization techniques used to sort out the problem of hydrothermal scheduling. These methods are devised on the local search through the feasible area of solution [4]. These techniques can be mathematical programming algorithms [5, 6] or the artificial intelligence schemes and the evolutionary methods.

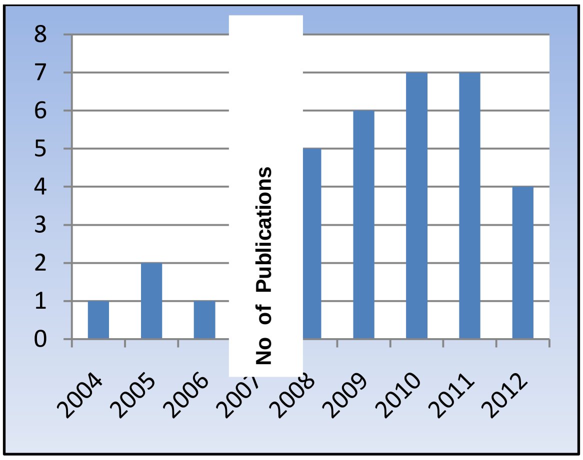
These techniques can be classified as deterministic and heuristic methods. The deterministic methods include Lagrangian relaxation and Benders decomposition methods, mixed-integer programming, dynamic programming and interior-point methods. The heuristic methods include Genetic algorithms, particle swarm optimization and other evolutionary techniques. Generally the short term hydrothermal scheduling issues are solved by the deterministic methods. The new stochastic heuristic methods which are population based, derivative free, can search in non smooth spaces and can be applied on linear or nonlinear objective functions. But the classical methods are found efficient in solving optimization problems [7]. This is due to easy availability of software tools and solid mathematical foundation.

The evolutionary methods are based on the theory of evolution. It takes its concept from Charles Darwin's theory of "survival of the fittest" [8]. These methods have been applied to solve complicated optimization problems [9]. The trademarks of these methods are flexibility and capability of getting good and optimum solutions. But the problem with these are requirements of computer and convergence [10]. The evolutionary computation techniques applied to power systems for optimization purpose include genetic algorithms, simulated annealing, evolutionary strategies, evolutionary programming and particle swarm optimization.

3. Particle Swarm Optimization

A swarm is a group of individuals or birds that are moving. These individuals move randomly but together. Particle swarm optimization is an evolutionary method. It has inspiration from the flock of birds or fish. This computing method is based on the movement of the group of birds and their intelligence involved in finding the location of food.

Particle Swarm Optimization was first introduced by James Kennedy and Russell Eberhart in 1995 [11, 12]. It is a powerful, stochastic algorithm to solve optimization problems specially which are non-linear. The method is very simple and can be implemented easily. It can solve and optimize complex objective functions. It does not require correct starting positions. But this method does not give a perfect solution mathematically nor does it always converge to a global minimum or maximum. [13]. The main weakness of this technique is its premature convergence particularly when dealing with those problems which have more local optima. To solve this issue Kennedy and Eberhart also proposed the idea of craziness. Whenever premature convergence occurs the crazy agents are set off and ultimately a better solution is found even in a difficult, complex field. Particle Swarm Optimization algorithms have been extensively used to solve various problems of power systems which require complex optimization. A complete analysis of PSO applications in different areas of power were presented [13]. Here the merits and demerits of the method were also highlighted.



Year of Publications

Figure 1. Number of papers published each year on STHTS based on PSO.

Although the work on PSO started in 1995 but research papers regarding PSO and Hydrothermal scheduling (searched from IEEE/IET/Elsevier databases) has been found from year 2004. Figure 1 shows the number of research papers on the topic of STHTS using PSO technique from 2004 to present (searched from IEEE/IET/Elsevier databases).

Wang Xin-xing [14] divided the particles into many clusters and named it as the refined algorithm of PSO to settle the problem of optimal load distribution in hydrothermal power systems. The optimization was verified by practical calculations. This refined PSO had faster convergence and the solutions found were more accurate than common PSO and genetic algorithms (GA).

A dispatch model for hydroelectric plant was presented by J. Chuanwen and E. Bompard [15]. The model was developed to achieve best results. Using particle swarm optimization they proposed a new algorithm that is self-adaptive and chaotic. Their algorithm worked better in a deregulated environment. The mapping of chaos and adaptive scaling term were introduced in his approach. Not only the rate of convergence but the precision were increased. When tested on a practical system the results were quite effective and robust when compared with the traditional method.

Umayal and Kamaraj [16] proposed an application to sort out the multi-objective optimization problem of short-term optimal generation schedule. Using this method the operation costs and emission were minimized while satisfying environmental constraints. Most of the constraints like emission control and others were taken into account except the ramp rates. The proposed algorithm was tried on two test systems and the results were found good. But the size of the examined systems was not very large. The proposed solution was simple and required less time.

A study of PSO its comparison to other search algorithms was done by M. Sinha and L.L Lai [17]. PSO method was found superior for solving the hydrothermal short term issue because it provided better convergence. The solution was also found in a less time.

S. Titus and A.E. Jeyakumar [18] resolved the hydrothermal coordination problem considering Prohibited Operating zones (POZ). The problem was non convex due to these zones. PSO was used to find a much better solution. The power balance, reservoir volume, water discharge and ramp limits were considered. The algorithm was improved using a craziness function. As compared to gradient search technique this approach provided a cheaper and better quality solution.

Different PSO versions were proposed by B. Yu et al. [19] to solve the scheduling problem of hydrothermal systems. Four versions of PSO were presented. These versions were compared also. The algorithms were applied to a test system with a number of hydro plants and one equivalent thermal plant. The pumped storage units were not incorporated while performing test. Better performance was shown by different PSO versions. The local versions of the method could retain the diversity in population and was found the pre-eminent.

T. Lee [20] used multiple pass iteration particle swarm optimization. He considered wind turbine generators present in the power systems. A new index called iteration best (IB) was used which improved solution quality. To improve and modify the computation efficiency the idea of multi pass dynamic programming was used. The technique starts with a coarse time phase and a searching space. The search space and the time interval in between two time stages are refined by pass by pass (iteration).

To optimize the cost of individual thermal units Mandal K.K [21] again employed PSO, however, he considered the effect of loading of valve point on the objective function and practical constraints. A test system that consisted of a number of hydro and thermal units with no pumped-storage units was employed. PSO algorithm was found superior when compared to simulated annealing (SA) and an evolutionary programming method.

C. Samudi et al. [22] presented a new algorithm using particle swarm. Different particle selections were analyzed and finally the reservoir volume was taken as the particle. The proposed scheme gave better results in comparison to other techniques. 300 tests were conducted and the success rate was found 100% for finding global optimum.

A hybrid technique of particle swarm optimization was proposed by J. Wu et al. [23] . His technique was based on chance-constrained programming and embedded with evolutionary algorithms. The Hybrid Particle Swarm Optimization (HPSO) surely converged to the global optimum result. The model was solved by combining HPSO and Monte Carlo simulations. A cascaded hydropower plant comprising three reservoirs and three power houses were tested with the technique. The hybrid approach provided a better solution and was able to maximize the objective profit throughout a time period. The constraints were also met with a specified probability.

X. Yuan and L. Wang [24] proposed an enhanced particle swarm optimization algorithm. The concept of repeller was included (the particle remembers its worst position). To effectively handle constraints chaotic sequences, viability based selection technique and a random selection were employed. The usefulness of this method was tested for the best daily production plan. The test results were better; the quality of their solution and convergence was superior in comparison to other methods.

P.K. Hota and A.K Barisal [25] presented a new method using improved particle swarm optimization. To speed up the optimization and inequality constraint handling the vibrant search space minimizing technique was used. The method was implemented on a hydrothermal system. The hydroelectric system was cascaded multi-reservoir system which had restricted operating zones. The thermal unit had valve point loading. The comparison was made with dynamic programming, non linear programming, evolutionary programming and differential evolution methods.

Another improved particle swarm optimization approach was presented by S. Liu and J. Wang [26]. An inertia weight technique which was self adaptive was employed. A penalty function was used to handle nonlinear constraints. When compared to others it showed a higher performance and good results.

Algorithms which resulted in an excellent optimized cost were presented [27] by Po-Hung. The convergence of the solution was robust. The encoding/decoding methods were also described. The algorithm was tested on three cascaded hydro units and 22 thermal plants.

Akbari Foroud [28] joined the least fuel cost and least emission, into a single function. The weighted sum method was utilized for this purpose. The weighing factors are tuned by means of some decision variables until a desired solution is obtained. An Efficient Particle Swarm Optimization technique was described for the combined function optimization. The star topology and random topology were joined to guide particles in searching. The overall search capability and convergence were enhanced because of this topology. The method was checked on a hydrothermal system with four cascaded reservoirs and three thermal plants. The results were compared with some newly printed methods in the field. These results verified the method is effective and robust.

A meta-heuristic technique employing Particle Swarm Optimization to portfolio optimization problem [29] was presented by N. Amjady and H.R Soleymanpour. The model was tested on different restricted and unrestricted risky investment portfolios. Its comparison with Genetic Algorithms was also done. This approach can construct optimal risky portfolios with high computational efficiency.

S. Lu and C. Sun [30] presented a changed quantum behaved particle swarm optimization. He used it to solve combined economic emission schedule of hydrothermal systems. He also considered many constraints. The fuel cost and pollutant emission was minimized. The presented method called Quantum based PSO with differential Mutation (QPSO-DM) combined the quantum behaved PSO algorithm with differential mutation operation. In differential mutation the classical evolution operator mutation is combined with simple arithmetic operations which can diversify the population. The search capability increased due to this combination. Various case studies were conducted and QPSO-DM was compared with other methods. The proposed method was found better in quality of solution, is robust and converged quickly.

Particle swarm optimization reached to the global optimum quickly and avoided local minimum operating point when S. Singh and N. Narang [31] applied it. A best solution was achieved while satisfying all the constraints.

The previously presented quantum behaved particle swarm optimization technique was improved by the same authors [32]. Heuristic strategies were employed to deal with the equality constraints. The water balance constraints, power balance constraints and the reservoir storage volumes constraints were handled. Different tests on economic load and emission scheduling and combined economic emission scheduling in hydrothermal scheduling were carried out. The test results were also compared with those of other methods.

S. Thakur and C. Boonchay [33] utilized a self organizing hierarchical particle swarm optimization with time varying acceleration coefficients (SPSO-

TVAC). This approach enabled him to reduce the thermal operating cost while the hydraulic and thermal generation constraints were fulfilled. Scheduling for multiple periods and operating cost function of thermal units which was non convex was taken into account. The proposed hydrothermal scheduling approach based on SPSO-TVAC provided a lower total cost when tested on different systems. Its comparison was also done to inertia weight approach particle swarm optimization (IWAPSO) and the existing optimization techniques and in all cases found better.

A fuzzy adaptive particle swarm optimization technique was proposed by W. Chang et al. [34, 35]. This technique could overcome the problems of premature convergence. The fuzzy adaptive principle was employed for inertia weight. The inertia weight was modified incorporating using the fuzzy laws and so a nonlinear function was optimized. The performance of method was checked on hydrothermal system having 1 thermal unit and 4 hydro plants. Its evaluation was also done with PSO and genetic algorithms and found better in solution quality and computational efficiency.

K.K. Mandal and N.Chakraborty [36, 38] proposed a reliable method called self organizing hierarchical particle swarm optimization. To avoid premature convergence time changing acceleration coefficients were enforced. A cascaded multiple chain hydrothermal system was studied having non-linear relation between the water discharge rates, generated power and total head. The method gave better results of fuel cost and emission output.

Mandal [37] afterwards developed an efficient PSO based algorithm. The algorithm was applied to cascaded reservoirs for combined economic emission scheduling. For problem formulation the cost and emission were considered. The algorithm was evaluated on a system with four cascaded hydro and three thermal units, and was also compared with other evolutionary programming methods.

The optimum hourly schedule of hydrothermal power system was found by S. Padmini [39, 40]. The algorithm was examined on a system consisting of each one hydro and thermal plant. The results were also compared with earlier works. The convergence characteristics of the method were excellent and the results obtained were effective and better in terms of cost of fuel and time for computation.

G. Sreenivasn [41] proposed an approach of particle swarm optimization. The thermal units were mathematically replaced by an equivalent unit. The system model incorporated the generated load power balance equations and net water discharge equation. In the algorithm constraints on the operational limits and on the reservoir volume were considered. The numerical findings showed that the algorithm was better than generic algorithm. It produced better solution quality and good convergence characteristics.

A small population-based optimization approach for the first time was presented by J. Zhang [42] . A new mutation operation was used to enhance the diversity of the population. A differential evolution (DE) algorithm was utilized as an acceleration operation. It helped to accelerate the convergence of the approach when the optimal result had no significant improvements after many iterations. A migration operation was used to keep the crowding diversity of the swarm above a desired level. Also a special repair procedure was used to take care of the complicated equality constraints. The scheme was found effective when was tested on three hydrothermal test systems. The results were also evaluated with those got by different evolutionary methods. The fuel costs and the performance of the proposed approach were excellent. It was shown that the small population based PSO (SPPSO) approach could provide a better solution at lesser computational time and effort.

J. Sasikala et al. [43] proposed an economic emission dispatch approach which was extremely efficient. The technique decreased number of variables. It showed better results on three test systems. It was found suitable for systems of any size.

Again an improved self adaptive particle swarm optimization algorithm was presented by W. Ying [44]. To avoid the issue of premature convergence the evolution path of every particle was changed by changing the two critical parameters of PSO. A new scheme was presented to tackle the different constraints. The algorithm was tested on four hydro units and an equal thermal unit. The results showed that the new scheme can get a better result. It was robust and accurate in comparison with the other methods.

4. Conclusion

This paper illustrates a review of the works printed on applying the Particle Swarm optimization method to workout the short-term hydrothermal scheduling issue. It is evident that the PSO approach has been found very efficient to find an optimal solution of hydrothermal scheduling. It can not only provide a better solution but decreases the computational time and effort. Different PSO methods techniques and algorithms developed are indicated and discussed. It can be considered a literature review and a listing of printed references on the PSO used to solve STHTS upto 2012.

References

[1] A.J. Wood and B.F. Wollenberg, Power Generation Operation and Control, John Wiley & Sons. New York (1996).

[2] M. El-Hawary and G. Christensen, International Journal of Control **16**, (1972) 1063.

[3] I. Farhat and M. El-Hawary, Electric Power Systems Research **79** (2009) 1308.

[4] Y.H. Song, Kluwer Academic Pub. **20** (1999).

[5] J.A. Momoh, R. Adapa and M. El-Hawary, IEEE Transactions on Power Systems **14** (1999) 96.

[6] J. Momoh, Electric Power System Applications of Optimization Marcel Dekker, Inc. New York (2001).

[7] S.S. Rao and S. Rao, Engineering optimization: theory and practice, Wiley (2009).

[8] D.B. Fogel, IEEE Spectrum **37** (2000) 28.

[9] V. Miranda, D. Srinivasan and L.M. Proenca, International Journal of Electrical Power & Energy Systems **20** (1998) 89.

[10] R. Bansal, International Journal of Emerging Electric Power Systems **2** (2011) 1.

[11] R. Eberhart and J. Kennedy, A New Optimizer Using Particle Swarm Theory, IEEE Proceedings of the Sixth International Symposium on Micro Machine and Human Science **4** (1995) p.1942.

[12] J. Kennedy and R. Eberhart, Particle Swarm Optimization, IEEE International Conference on Neural Networks (1995).

[13] M. AlRashidi and M. El-Hawary, IEEE Transactions on Evolutionary Computation **13** (2009) 913.

[14] X. Wang and M. Zhang, Power System Technology **12** (2004).

[15] J. Chuanwen and E. Bompard, Energy Conversion and Management **46** (2005) 2689.

[16] S.P. Umayal and N. Kamaraj. Annual IEEE (INDICON) (2005).

[17] N. Sinha and L.L. Lai, Meta Heuristic Search Algorithms for Short-Term Hydrothermal Scheduling, IEEE International Conference on Machine Learning and Cybernetics (2006) 4050.

[18] S. Titus and A.E. Jeyakumar, International Journal of Soft Computing **2** (2007) 313.

[19] B. Yu, X. Yuan and J. Wang, Energy Conversion and Management **48** (2007) 1902.

[20] T.-Y. Lee, Energy Conversion and Management **49** (2008) 751.

[21] K.K. Mandal, M. Basu and N. Chakraborty, Applied Soft Computing **8** (2008) 1392.

[22] C. Samudi, IEEE Conference and Exposition on Transmission and Distribution (2008).

[23] J. Wu, J. Zhu, G. Chen and H. Zhang, IEEE Transactions on Power Systems **23** (2008) 1570.

[24] X. Yuan, L. Wang and Y. Yuan, Energy Conversion and Management **49** (2008) 2966.

[25] P.K. Hota, A.K. Barisal and R. Chakrabarti, Electric Power Systems Research **79** (2009) 1047.

[26] S. Liu and J. Wang, An Improved Self Adaptive Particle Swarm Optimization Approach for Short-Term Scheduling of Hydro System, IEEE International Asia Conference on Informatics in Control, Automation and Robotics, CAR'09 (2009) 334.

[27] C. Po-Hung, Li-Ming, An Liu and C. Hung Cheng, International Conference on Energy and Environment Technology (2009).

[28] A. Akbari Foroud and H.R. Soleymanpour. 18th Iranian Conference on Electrical Engineering (2010).

[29] N. Amjady and H.R. Soleymanpour, Electric Power Systems Research **80** (2010) 723.

[30] S. Lu, C. Sun and Z. Lu, Energy Conversion and Management **51** (2010) 561.

[31] S. Singh, and N. Narang, http://dspace.thapar.edu:8080/dspace/handle/10266/1234 (2010).

[32] C. Sun and S. Lu, Expert Systems with Applications **37** (2010) 4232.

[33] S. Thakur, C. Boonchay and W. Ongsakul. IEEE Power and Energy Society General Meeting (2010).

[34] C. Wenping, Asia-Pacific Conference Power and Energy Engineering (2010).

[35] W. Chang, Energy and Power Engineering **2** (2010) 223.

[36] K. Mandal and N. Chakraborty, Expert Systems with Applications (2011).

[37] K.K. Mandal and N. Chakraborty, Applied Soft Computing **11** (2011) 1295.

[38] K.K. Mandal and N. Chakraborty, Smart Grid and Renewable Energy **2** (2011) 282.

[39] S. Padmini and C.C.A. Rajan. International Conference on Sustainable Energy and Intelligent Systems (2011).

[40] S. Padmini, C. Rajan and P. Murthy, Swarm, Evolutionary and Memetic Computing (2011) 176.

[41] G. Sreenivasan, C. Saibabu and S. Sivanagaraju, International Journal of Advanced Computer Science and Applications **2** (2011) 97.

[42] Z. Jingrui, W. Jian and Y. Chaoyuan, IEEE Transactions on Power Systems **27** (2012) 142.

[43] J. Sasikala and M. Ramaswamy, Electrical Engineering (Archiv fur Elektrotechnik) (2012) 1.

[44] W. Ying et al., Expert Systems with Applications **39** (2012) 2288.