GoddumarriTejaswara, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 10, Issue 9, (Series-II) September 2020, pp. 06-11

RESEARCH ARTICLE OPEN ACCESS

Particle Swarm Optimization for Multi-Area Economic Dispatch with Tie-Line Capacity Constraints

GoddumarriTejaswara*, M.Damodar Reddy**
**(Department of Electrical and Electronics Engineering, SV University College of Engineering, Tirupati-517502.*
*** (Department of Electrical and Electronics Engineering, SV University College ofEngineering, Tirupati-517502 .*

ABSTRACT
This paper presents particle swarm optimization (PSO) for solving multi-area economic dispatch (MAED) problem with tie line limits. A constriction factor is applied to the regular PSO to ensure the convergence. The effectiveness of the proposed method is tested and verified on the two different systems. First system is a small power system with six generating units divided into two areas connected by a single tie-line, whereas the second system is a medium power system with sixteen generating units divided into four areas connected by six tie-lines. This algorithm gives a promising approach to solve the multi-area economic dispatch problem in practical power systems. The results obtained through the proposed method are compared with those reported in the literature.
***Keywords*–**ELD, MAED, PSO

Date of Submission: 29-08-2020 Date of Acceptance: 14-09-2020

I. INTRODUCTION

The Economic load dispatch (ELD) is a large scale non-linear allocation problem in power system operation. ELD is allocating the number of committed generators to the given load demand economically while meeting the various operating constraints [1]. Multi-area economic dispatch (MAED) is an extension of the Economic load dispatch. MAED determines the generation level and the interchange power between areas such that the fuel cost in all areas is minimized while satisfying power balance constraints, generating limits and tie-line constraints.

The ELD is traditionally solved by considering the cost function for the generating units has been approximated as a quadratic function. The lambda-iteration method and gradient method were used to solve the ELD problem. The study of MAED was first done by Shoults in 1980. He solved economic dispatch considering import and export constraints between areas [2]. Romano proposed a decomposition principle to solve constrained economic dispatch with multi area systems [3]. An algorithm based on newton-raphson’s method for multi-area economic dispatch and calculation of short range margin cost based prices was presented by Wernerus and Soder [4]. Streiffert proposed Network flow models for solving the multi-area economic dispatch [5]. Yalcinoz and short used Hopfield neural network approach for solving multi-area economic dispatch [6].

Stochastic search techniques like genetic algorithm, simulated annealing are being employed in recent days to find the global optimal solution. Jeyakumar, Jayabarathi and Raghunathan solved various types of economic dispatch problems by Particle swarm optimization [7]. Manoharan solved the multi-area economic dispatch problems by various evolutionary algorithms [8]. Artificial bee colony optimization for MAED was proposed by M Basu [9]. A differential evolution particle swarm optimizer for various types of MAED problems was presented by Ghasemi [10]. Jain and Pandit discussed on reserve constrained MAED employing differential evolution and time-varying mutation [11]. Prasanna et al. [12] solved the Security Constrained Economic Dispatch in interconnected power system by using Fuzzy logic strategy incorporated with Evolutionary Programming and with Tabu-Search algorithms.

In the present paper, Particle swarm optimization (PSO) with constriction factor has been used to solve various MAED problems. The PSO method is a member of the wide category of swarm intelligence methods, which was first introduced by American social psychologist James Kennedy and electrical engineer Russel C. Eberhart in 1995 [13]. PSO is a Swarm Intelligence based method inspired by the cooperative behaviour observed in social animals in nature [13]. The proposed method combines the original PSO algorithm with a constriction factor. The Constricted Original PSO incorporates a constriction factor to the PSO, which ensures convergence and improves the fine-tuning of the search.

II. PROBLEM FORMULATION

The main objective of the multi-area economic dispatch is to determine the generation levels and the power interchanges between the areas that would minimize the total operating cost in all areas while meeting the power balance, generator limits and tie-line limit constraints. The objective function for MAED problem can be written as

$$\min \sum_{m=1}^{M} F_m = \sum_{m=1}^{M} \sum_{n=1}^{N_m} (a_{mn} P_{mn}^2 + bmnPmn + cmn) \qquad (1)$$

Where N_m is the number of on-line units for the area *m* in a *M* area system

a_{mn}, b_{mn}, c_{mn} are the fuel cost co-efficient and

P_{mn} is the power output of the generator *n* in area *m*.

The minimization is subjected to the following constraints:

2.1 Area power balance constraint

$$\sum_{n=1}^{N_m} P_{mn} = P_{Dm} + P_{Lm} + \sum_{k,k\neq m} T_{mk}$$
$$for\ m \in M \qquad (2)$$

The transmission loss $P_{Lm}$of area m maybe expressed by using B-coefficients as

$$P_{Lm} = \sum_{i=1}^{N_m} \sum_{j=1}^{N_m} P_{mi} B_{mij} P_{mj} + \sum_{j=1}^{N_m} B_{0mj} P_{mj} \quad (3)$$

Where P_{Dm} is the real power demand of area *m*.$T_{mk}$is the tie-line real power transfer from area *m* to area *k*. $T_{mk}$is positive when power flows from area *m* to area *k* and T_{mk} is negative when power flows from area *k* to area *m*.

2.2Real power generation capacity constraints

The real power generated by each generator should be within its lower and upper limits givens as

$$P_{mn,min} \leq P_{mn} \leq P_{mn,max} \quad (4)$$

2.3 Tie-line capacity constraints

The tie-line real power transfer $T_{mk}$from area m to area k should not exceed the tie-line transfer capacity given below as

$$T_{mk,min} \leq T_{mk} \leq T_{mk,max} \quad (5)$$

2.4 Prohibited operating zone

The prohibited operating zones are defined as that range of the power output of any generator for which the operation causes undue vibration of the turbine shaft bearing caused by opening or closing of the steam valve. These undue vibrations may cause damage to the shaft and the bearings. Hence operation is avoided in such regions. For units with prohibited zones, these are the additional constraints on the unit operating range

$$P_{j,,min} \leq P_j \leq P_j^l$$
$$P_{j,k-1}^u \leq P_j \leq P_{j,k}^l \qquad k = 2,3,\ldots Z_j \quad (6)$$
$$P_{j,z_j}^u \leq P_j \leq P_{j,max}$$

Where $P_{j,k}^l$ and $P_{j,k}^u$ are the lower and upper bounds of the *k*th prohibited zone of unit *j* and *Zj* is the number of prohibited zones of unit *j*.

III. PARTICLE SWARM OPTIMIZATION

PSO algorithm is a population based meta-heuristic search method that is motivated from simulation of the behaviour of social systems such as fish schooling and birds flocking. It was first introduced in the year 1995 by Kennedy and Eberhart . In PSO system, particles fly around in a multidimensional search space. During this flight, each particle adjusts its position according toits own experience and the experience of the neighboring particles, making use of the best position encountered by itself and its neighbors. The swarm direction of a particle is defined by the set of particles neighboring the particle and its history experience.

Based on the above description, the PSO algorithm can be formulated as follows. Let *P* be the particle position and V be its velocity in the workspace. For any *i*-th particle in the total population, the position of the *i*-th particle is given as $P_i = (P_{i1}, P_{i2}, P_{i3}, \ldots, P_{id})$ in the *d*-dimensional space. The previous best position of the *i*-th particle is recorded and represented as $Pbest_i = (Pbest_{i1}, Pbest_{i2}, Pbest_{i3}, \ldots Pbest_{id})$. The best particle among all the *Pbest* is represented as *gbest*. The corresponding velocity of the *i-th* particle is given as $V_i = (V_{i1}, V_{i2}, V_{i3}, \ldots, V_{id})$. The particle tries to modify tries to modify its position using the current velocity and the distance from *Pbest* and *gbest*. The modified velocity of each particle can be formulated as an equation.

$$V_{id}^{(iter+1)} = w * V_{id}^{(iter)} + c_1 * rand1 * \left(Pbest_{id} - P_{id}^{(iter)}\right) + c_2 * rand2 * \left(gbest_i - P_{id}^{(iter)}\right) \quad (7)$$

$$P_{id}^{(iter+1)} = P_{id}^{(iter)} + V_{id}^{(iter+1)} \quad (8)$$

i= 1,2,3,…I and d=1,2,3…,m

where,
I is the number of particles
m is the number of dimensions in the particle
w is the inertia weight factor
c_1,c_2 are the acceleration constants
rand1, rand2 are the random value in range [0,1]
$V_{id}^{(iter)}$ is the velocity of the *i*th particle in *d*th direction, $V_d^{min} \le V_{id}^{(iter)} \le V_d^{max}$
$P_{id}^{(iter)}$ is the current position of *i*th particle in the *d*th dimension at the iteration *iter*

By suitably selecting the inertia weight *w*, we can provide a balance between global and local explorations, thus requiring lesser number of iteration on average to find an optimal solution. As originally developed, *w* is often linearly decreased from 0.9 to 0.4 during a run. It is generally put by following equation

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \quad (9)$$

Where $iter_{max}$ isthe maximum number of iterations and *iter* is the current iteration.

The acceleration constants $c_1$andc_2 represent the weighting of the stochastic acceleration terms that pull each particle toward the *Pbest* and *gbest* positions. Low values allow particles to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement toward, or past, target regions. Hence, the acceleration constants $c_1$and$c_2$were often set to be 2.0 according to the past experience.

3.1 Constriction factor approach

Clerc [14] in his study on stability and convergence of PSO have introduced a constriction factor K. Clerc indicates that the use of a constriction factor may be necessary to insure convergence of the particle swarm algorithm.The basic system equations of the PSO (7-8) can be considered as a kind of difference equations. Therefore, the system dynamics, namely, the search procedure, can be analysed by the Eigen value analysis and can be controlled so that the system has the following features.
a) The system converges,
b) The system can search different regions efficiently by avoiding premature convergence.
In order to insure convergence of the PSO algorithm, the velocity of the constriction factor based approach can be expressed as follows

$$V_{id}^{(iter+1)} = K \begin{bmatrix} w * V_{id}^{(iter)} + c_1 * rand1 * \left(Pbest_{id} - P_{id}^{(iter)}\right) \\ + c_2 * rand2 * \left(gbest_i - P_{id}^{(iter)}\right) \end{bmatrix} \quad (10)$$

$$K = \frac{2}{2 - \emptyset - \sqrt{\emptyset^2 - 4\emptyset}} \quad (11)$$

Where $\emptyset = c_1 + c_2$, $\emptyset > 4$

The convergence characteristic of the system can be controlled by ϕ. In the constriction factor approach, the ϕ must be greater than 4.0 to guarantee stability.

IV. DEVELOPMENT MAED BY THE PSO ALGORITHM

In this paper, MAED problem is solved using a PSO algorithm with constriction factor within power system operation. Its implementation is given in following steps

STEP1
Let
P_n=[(P_{11},P_{12},…P_{1N1}),…(P_{i1},P_{i2},…P_{iN2}),…(P_{M1},P_{M2},…P_{NM}),(T_{12},T_{13}…T_{1N}),(T_{23},T_{34}…T_{2N})…. $T_{(N-1)N}$]
be the nth particle of a population n=1,2,….I.
The elements of the P_n are real power outputs of the generators of all areas and tie-line power flows. The particles must be generated in the range following equations (4) to (6).

STEP 2
The particle velocities are generated randomly in the range [-V_d^{max},V_d^{max}].
The maximum velocity limit in the *d*th dimension is computed as follows

$$V_d^{max} = \frac{P_{d,max} - P_{d,min}}{R}$$

Where R is the chosen number of intervals in the *d*th dimension.

STEP 3
Objective function values of the particles are evaluated using equation (1). These are recognised as Pbest of the particles.

STEP 4
The best value among all the Pbest are identified as gbest.

STEP 5
New velocities of all dimensions are calculated using equation (10).

STEP 6

The positions of each particle is updated using equation (8).
STEP 7
The objective function values are calculated for the updated positions of the particles.
If the new value is better than the previous Pbest, the new value is set to be Pbest. If the stopping criteria is met, the positions of particles represented by gbest are the optimal solution. Otherwise the procedure is repeated from step 4.

V. NUMERICAL EXAMPLES AND RESULTS

The performance of PSO with constriction factor for MAED has been evaluated by using two test systems.

5.1Test system 1

Test system 1 is a small power system network with two areas and each areas contains three generators. All the generators have prohibited operating zones (POZ). Transmission loss is considered. The generator data has been taken from [4]. The total real power load demand is 1263 MW and that the percentage of load demands in area 1 and area 2 are 60% and 40% respectively. The tie-line power flow limit is 100 MW. The results obtained by the proposed method are presented in Table 1.

T**able1**. Simulation results for the test system 1

AREA	UNIT	GENERATION (MW)
1	P_1	500.000
	P_2	200.000
	P_3	150.000
2	P_4	204.325
	P_5	154.685
	P_6	67.5595
Tie-line power	T_{12}	82.8014
Power loss	P_{L1}	9.4269
	P_{L2}	4.1880
Cost($/hr)		12255.1781

The results are compared with other algorithms which are tested on the same test system. For comparison, artificial bee colony optimization (ABCO) and differential evolution (DE) methods are chosen. Results obtained are validated in the Table 2.

Table 2 Comparison of the simulation results for test system1

AREA	GENERATION	PSO	ABCO	DE
1	P_1(MW)	500.000	500.000	500.000
	P_2(MW)	200.000	200.000	200.000
	P_3(MW)	150.000	149.999	150.000
2	P_4(MW)	204.325	204.335	204.334
	P_5(MW)	154.685	154.995	154.704
	P_6(MW)	67.5595	67.291	67.577
Tie-line power	T_{12}(MW)	82.8014	82.772	82.773
Power loss	P_{L1}(MW)	9.4269	9.4269	9.4269
	P_{L2}(MW)	4.1880	4.1955	4.1890
Cost($/hr)		12255.1781	12255.39	12255.42

5.2 Testsystem 2

This test system consists of a four area system interconnected by six tie lines. The cost co-efficients, generator data and tie line limits are taken from [5].The system is a medium scale test system with sixteen generating units divided into four areas with four generators in each and six tie lines interconnecting them. The active load demand are set to 400MW for area 1, 200MW for area 2, 350MW for area 3 and 300MW for area 4. The obtained results of PSO with constriction factor algorithm for the test system 2 are tabulated in Table 3.

Table 3 Simulation results for the test system 2

AREA	UNIT	GENERATION (MW)
1	P_1	150.00
	P_2	100.00
	P_3	67.879
	P_4	99.996
2	P_5	56.039
	P_6	95.251
	P_7	41.452
	P_8	72.192
3	P_9	50.00
	P_{10}	36.173
	P_{11}	38.288
	P_{12}	37.165
4	P_{13}	149.999
	P_{14}	100
	P_{15}	58.611
	P_{16}	96.752
Tie-line	T_{12}	0.0027

powers	T_{13}	17.931
	T_{14}	0.0009
	T_{23}	69.926
	T_{24}	-4.948
	T_{34}	-99.9981
Total power generated (MW)		1249.90
Cost($/hr)		7335.89

Here negative tie-line power in T_{24} indicates that power is being imported to area 2 from area 4. Similarly, negative T_{34} indicates power is imported to area 3 from area 4.The results are compared with other algorithms which are tested on the same test system. For comparison, classical evolutionary programming (CEP) and network flow programming method (NFP) algorithms are chosen. Results obtained are validated in the Table 4.

Table 4 Comparison of the simulation results for test system 2

AREA	GENERATION	PSO	CEP	NFP
1	P_1(MW)	150.00	150.00	150.00
	P_2(MW)	100.00	100.00	100.00
	P_3(MW)	67.879	68.826	66.971
	P_4(MW)	99.996	99.985	100.00
2	P_5(MW)	56.039	56.373	56.970
	P_6(MW)	95.251	93.519	96.250
	P_7(MW)	41.452	42.546	41.870
	P_8(MW)	72.192	72.647	72.520
3	P_9(MW)	50.00	50.00	50.00
	P_{10}(MW)	36.173	36.399	36.270
	P_{11}(MW)	38.288	38.323	38.490
	P_{12}(MW)	37.165	36.903	37.320
4	P_{13}(MW)	149.999	150.00	150.00
	P_{14}(MW)	100	100.00	100.00
	P_{15}(MW)	58.611	56.648	57.050
	P_{16}(MW)	96.752	95.826	96.270
Tie-line powers	T_{12}(MW)	0.0027	-0.018	0.0
	T_{13}(MW)	17.931	19.587	18.180
	T_{14}(MW)	0.0009	-0.758	-1.210
	T_{23}(MW)	69.926	68.861	69.73
	T_{24}(MW)	-4.948	-1.789	-2.11
	T_{34}(MW)	-99.9981	-99.9927	-100
Cost($/hr)		7335.89	7337.75	7337.00

The results show that the PSO with constriction factor algorithm has been successfully implemented to solve the MAED problem with generator constraints.

VI. CONCLUSION

In this paper, PSO with constriction factor algorithm is proposed for solving MAED problem. In this study, a two area system with six generators and a four area system with sixteen generators are evaluated using the proposed algorithm and the results are compared with existing algorithms. It is seen from the comparisons that PSO with constriction factor has the ability to converge with better quality for MAED problem.

REFERENCES

[1]. Wood A.J. and B.F. Wollenberg. 1996. *Power Generation,Operation and Control, 2nd Edition*, New York: John Wiley &Sons.

[2]. Shoults RR, Chang SK, Helmick S, Grady WM. A practical approach to unit commitment, economic dispatch and savings allocation for multiple-area pool operation with import/export constraints, IEEE Trans Power AppartSyst 1980; 99(2):625-35.

[3]. Romano R, Quintana VH, Lopez R, Valadez V. Constrained economic dispatch of multi-area systems using the DantzigeWolfe decomposition principle. IEEE Trans Power ApparSyst 1981;100(4):2127e37.

[4]. Wernerus J, Soder L. Area price based multi-area economic dispatch with tie line losses and constraints. In: IEEE/KTH Stockholm power tech conference, Sweden; 1995. p. 710–5.

[5]. Streiffert D. Multi area economic dispatch with tie line constraints. IEEE Trans Power Syst 1995;10(4):1946e51.

[6]. Yalcinoz T, Short MJ. Neural networks approach for solving economic dispatch problem with transmission capacity constraints. IEEE Trans Power Syst 1998;13(2):307–13.

[7]. Jeyakumar DN, Jayabarathi T, Raghunathan T. Particle swarm optimization for various types of economic dispatch problems. Int J Electr Power Energy Syst 2006;28(1):36e42.

[8]. Manoharan PS, Kannan P.S, Baskar S, WilljuiceIruthayarajan M. "Evolutionary algorithm solution and KKT based optimality verification to multi-area economicdispatch". International Journal of Electrical Power & Energy Systems. vol.31,No.7-8,pp.365-373,2009.

[9]. Basu M. Artificial bee colony optimization for multi-area economic dispatch.Int J Electr Power Energy Syst 2013;49:181e7.

[10]. M Ghasemi, J Aghaei, E Akbari, S Ghavidel, Li Li. A differential evolution particle swarm optimizer for various types of multi-area economic dispatch problems, Energy 107 (2016) 182-195

[11]. Jain K., Pandit M., Srivastava L. Reserve constrained multi-area economic dispatch employing differential evolution with time varying mutation, Int. J.Electr. Power Energy Syst.,2012,39,(1).

[12]. Prasanna. T. S, and Somasundaram. P. "Multi-area security constrained economic dispatch by fuzzy-stochastic algorithms, Journal of Theoretical & Applied Information Technology . vol.5,No.1,pp.88-94,2009.

[13]. Kennedy J, Eberhart RC. Particle swarm optimization.Proc IEEE IntConf Neural Netw, Perth, WA Nov./Dec. 1995:1942e8.

[14]. Clerc M. 1999. “The swarm and the queen: towards a deterministic and adaptive particle swarm optimization,” Proceedings of the 1999 Congress on Evolutionary Computation, Vol. 3, pp. 1951-1957.

GoddumarriTejaswara, et. al. “Particle Swarm Optimization for Multi-Area Economic Dispatch with Tie-Line Capacity Constraints.” *International Journal of Engineering Research and Applications (IJERA)*, vol.10 (09), 2020, pp 06-11.