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Fuzzy Controlled Parallel PSO to Solving Large Practical Economic Dispatch

Belkacem Mahdad, Member, IEEE, K. Srairi, T. Bouktir, M. EL. Benbouzid, Senior Member, IEEE

Abstract—This paper presents a fuzzy controlled parallel particle swarm optimization approach based decomposed network (FCP-PSO) to solving the large economic power dispatch with non-smooth cost fuel functions. The proposed approach combines practical experience extracted from global database formulated in fuzzy rules, the adaptive PSO executed in parallel based in decomposed network procedure as a local search to enhance the search space around the global search. The robustness of the proposed modified PSO tested on 40 generating units with prohibited zones and compared with recent hybrid global optimization methods. The results show that the proposed approach can converge to the near solution and obtain a competitive solution at critical situation and with a reasonable time.

Key Words—Parallel Genetic Algorithm, Decomposed Network, PSO, economic dispatch, Fuzzy logic, Fuzzy Controlled, Planning and control.

I. INTRODUCTION

The economic dispatch problem (EDP) is one of the important problems in modern power system operation and planning. In its most general formulation, the economic power dispatch (EPD) is a nonlinear, nonconvex, large-scale, static optimization problem with both continuous and discrete control variables. The global optimization techniques known as genetic algorithms (GA), simulated annealing (SA), tabu search (TS), and evolutionary programming (EP), which are the forms of probabilistic heuristic algorithm have been successfully used to overcome the non-convexity problems of the constrained ED [1].

The literature on the application of the global optimization in the OPF problem is vast and [1] represents the major contributions in this area. In [2] authors presented an improved coordinated aggregation-based particle swarm optimization (ICA-PSO) algorithm for solving the optimal economic dispatch, the obtained results are compared to many large recent heuristic optimization techniques (HOT) given in the literature. Authors in [3] present a new fuzzy hybrid particle swarm optimization algorithm for non-linear, non-smooth and non-convex economic dispatch problem. In [4] authors present a novel string structure for solving the economic dispatch through genetic algorithm (GA). To accelerate the search process authors in [5] proposed a

multiple tabu search algorithm (MTS) to solve the dynamic economic dispatch (ED) problem with generator constraints, simulation results prove that this approach is able to reduce the computational time compared to the conventional approaches. PSO algorithm is one of the modern heuristic evolutionary techniques widely used in recent years and suitable to solve large-scale nonconvex optimization problem.

PSO has parallel search techniques. Due to its high potential for global optimization, PSO has received great attention in solving optimal power flow (OPF) problems with consideration of discontinuous fuel cost functions. The main advantages of the PSO algorithm are: simple concept, easy implementation, and computational efficiency. Although the PSO-based approaches have several disadvantages, it may get trapped in a local minimum when handling heavily constrained problems due to the limited local/global searching capabilities. Many hybrid methods have been proposed to enhance the performance of the standard PSO algorithm [7-15].

In general to overcome the drawbacks of the conventional methods related to the form of the cost function, and to reduce the computational time related to the large space search required by many global optimization methods, authors in [6-16-17] proposed an efficient decomposed GA for the solution of large-scale OPF with consideration of shunt FACTS devices under severe loading conditions. This paper presents an efficient combined approach based fuzzy rules and PSO based decomposed network to enhance the global solution of large economic dispatch with consideration of practical generator constraints.

II. ACTIVE POWER DISPATCH WITH DISCONTINUOUS FUEL COST FUNCTIONS

The main role for economic dispatch is to minimize the total generation cost of the power system but still satisfying specified constraints (generators constraints and security constraints).

A. ED with smooth cost function

For optimal active power dispatch, the simple objective function f is the total generation cost as expressed follows:

$$\text{Min } f_T = \sum_{i=1}^{N_g} (a_i + b_i P_{gi} + c_i P_{gi}^2) \quad (1)$$

where;

f_T : total generation cost;

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P_{gi} : active power generation at unit i ;
 a_i, b_i, c_i : cost coefficients of the i^{th} generator;
 N_g : is the number of generators.

B. ED with non-smooth cost function with valve-point loading effects

The ED with valve-point effect can be represented as a nonsmooth optimization problem having complex and nonconvex features with heavy equality and inequality constraints. The valve-point loading is taken in consideration by adding a sine component to the cost of the generating units. Typically, the fuel cost function of the generating units with valve-point loadings is represented as follows:

$$f_T = \sum_{i=1}^{N_g} (a_i + b_i P_{gi} + c_i P_{gi}^2) + \left| d_i \sin(e_i (P_i^{\min} - P_i)) \right| \quad (2)$$

d_i and e_i are the cost coefficients of the unit with valve-point effects. The input-output performance curve for a typical thermal unit can be represented as shown in Fig 1.

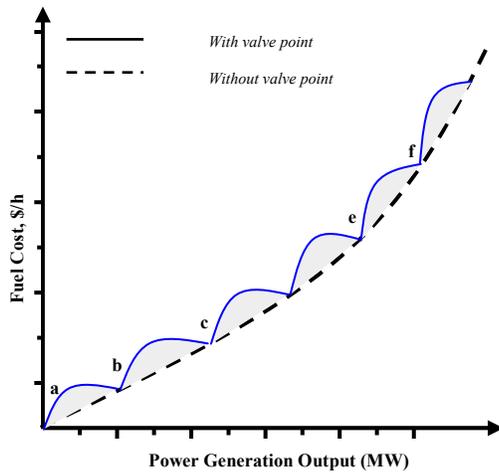


Fig 1 Input-Output curve under valve-point loading

C. The equality constraints:

For active power balance, the total generated power should be the same as the total demand plus the total power loss.

$$\sum_{i=1}^{NG} P_{gi} - P_D - P_{loss} = 0 \quad (3)$$

where P_D is the total active power demand, P_{loss} represent the transmission losses.

D. The inequality constraints:

Power output of generator should be within its minimum and maximum limits. The inequality constraint for each generator expressed as follows:

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad (4)$$

where P_{gi}^{\min} and P_{gi}^{\max} are the minimum and maximum active power generation limits of generator i , respectively.

III. FUZZY RULES CONTROLLED PSO

A. Overview of PSO Method

Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart in 1995 [11] is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving complex optimization system. The mathematical model for PSO is as follows.

$$V_i^{k+1} = \omega V_i^k + c_1 \text{rand} \times (P_{best_i}^k - X_i^k) + c_2 \text{Rand} \times (G_{best}^k - X_i^k) \quad (5)$$

where;

V_i^k : velocity of particle i at iteration k ;
 ω : inertia weight factor;
 c_1, c_2 : acceleration constant;
 X_i^k : position of particle i at iteration k ;
 $P_{best_i}^k$: best position of particle i until iteration k ;
 G_{best}^k : best position of group until iteration k ;

Once the velocity has been determined it is simple to move the particle to its next location, and a new coordinate X_i^{k+1} is computed for each of the N dimensions according to the following equation:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (6)$$

B. Hybrid-Modified PSO based ED

For better results and to get faster convergence, conventional PSO methods have been modified. In recent years various combined techniques have been studied to achieve this objective, these include [2]:

- Simulated annealing-PSO (SA-PSO).
- Quantum-Inspired version of the PSO using the harmonic oscillator (HQ-PSO).
- Particle swarm optimization with chaotic and Gaussian approaches (PSO-CG).
- Self-organizing hierarchical particle swarm optimization (QOH-PSO).
- Modified particle swarm optimization (MPSO).
- Hybrid particle swarm optimization with sequential quadratic programming (PSO-SQP).
- Improved coordinated aggregation-based PSO (ICA-PSO).

C. Why Fuzzy Logic Method?

The use of fuzzy logic has received increased attention in recent years because of its usefulness in reducing the need for complex mathematical models in problem solving. Fuzzy logic employs linguistic terms, which deal with the causal relationship between input and output variables. For this reason, the approach makes it easier to manipulate and solve problems.

This approach proposes a flexible PSO Algorithm based on fuzzy logic rules with the ability to adjust dynamically three parameters:

- Inertia weight, 'w'
- The two learning factors 'c1' and 'c2'.

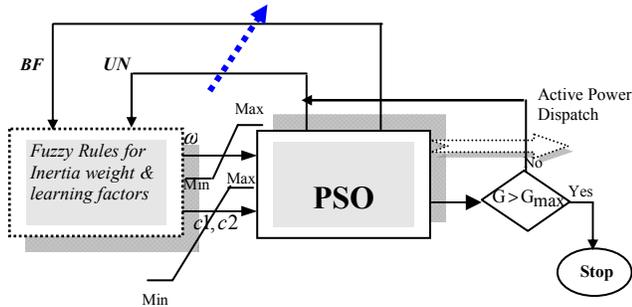


Fig. 2 Block diagram of the PSO parameters adjustment.

Fig. 2 presents the proposed block diagram of a fuzzy controlled PSO.

Inertia weight (w) and the two learning factors are considered critical for PSO convergence. A suitable value for weighing factor and learning factors provides balance between global and local exploration abilities and consequently results in a reduction of the number of iterations required to locate the optimum solution. Experimental results based in application of PSO to many practical networks at normal and abnormal conditions with load incrementation indicated, that it is better to adjust dynamically the value of the three parameters (w , c_1 and c_2) to assure convergence to the near global solution. c_1 and c_2 are scaling factors that determine the relative 'pull' of p_{best} and g_{best} . c_1 is a factor determining how much the particle is influenced by the memory of his best location, and c_2 is a factor determining how much the particle is influenced by the rest of the swarm. So if $c_1 > c_2$, the particle has the tendency to converge to the best position found by itself p_{best} rather than the best position found by the population g_{best} .

The proposed approach employs in the first stage practical rules interpreted in fuzzy logic rules to adjust dynamically the three parameters (inertia weight, and the two learning factors) during execution of the PSO algorithm, in the second stage parallel execution of PSO based decomposed network [6-16].

1) Membership Function Design

The membership function adopted by engineer differences from person to person and depends in problem difficulty therefore they are rarely optimal in terms of reproduced desired output.

2) Inputs and Outputs of Fuzzy Controller:

The main role of this controller is to improve the global searching capability and to increase the probability of escaping from a local minimum. A mechanism search based fuzzy rules designed to adjust dynamically the PSO parameters. The inputs of the proposed search mechanism based fuzzy controller are: changes of the best fitness which reflect the diversity in the cost generation, and the number of generation for unchanged fitness, the output is the variation in weighting factor and the variation in learning (acceleration) factors. The membership functions of inputs and outputs variables are shown in Fig. 3. Sample fuzzy rules for weight factor and learning factors are presented in Fig. 4.

In this study, the upper and lower value for weighting factor and for the two learning factors, respectively are changed based in membership functions for each variable from 1.3 to 0.3 and from 1 to 2. The final values of inertia weight 'w' and for the learning factors are calculated based on the fuzzy mechanism search presented in Fig. 2.

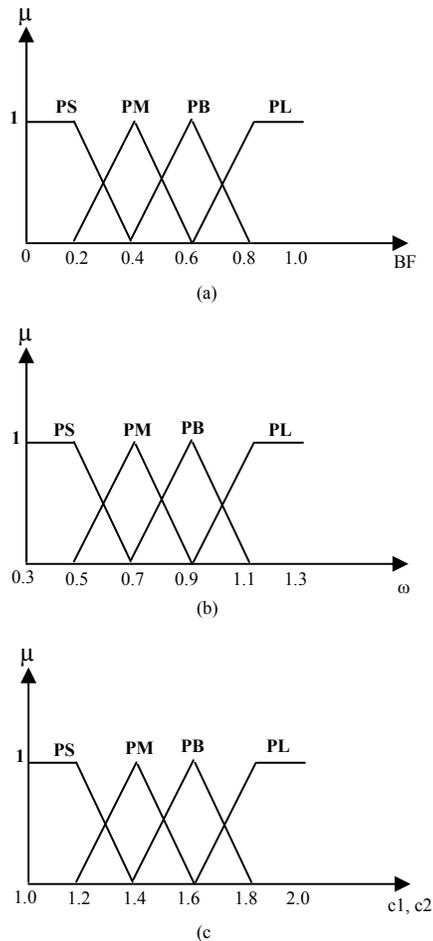


Fig 3 Membership functions: (a) best fitness Bf, (b) weighting factor w , (c) learning factors c_1, c_2 .

Where NP the number of partition;
 $Pd1$: the active power demand for the first initial partition.
 $Pd2$: the active power demand for the second initial partition.
 PD : the total active power demand for the original network.
The following equilibrium equation should be verified for each decomposed level:
For level 1:

$$Pd1 + Pd2 = PD + Ploss \quad (16)$$

2. Final Search Mechanism

- All the sub-systems are collected to form the original network, global data base generated based on the best results U_{best}^{Parti} of partition 'i' found from all sub-populations.
- Migration Procedure

The migration operation is newly introduced in the parallel PSO mechanism, thereby can effectively explore and exploit promising regions in a search space. This new mechanism based migration between individuals from different subsystems makes the swarm to react more by changing experiences.

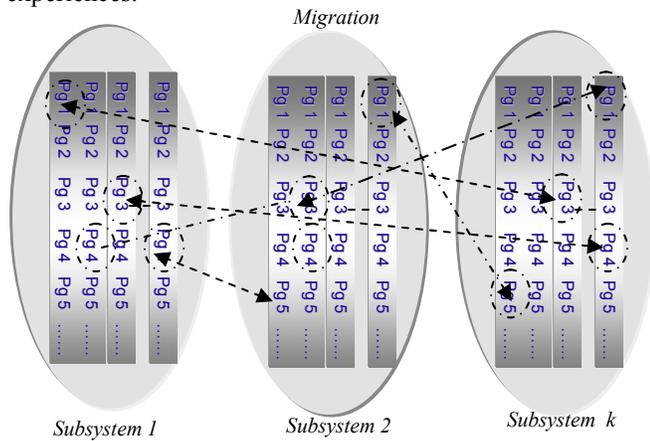


Fig 6 Illustration of the migration operation.

Fig 6 shows the mechanism of migration operation between individual from different subsystems.

- Choose arbitrary two subsystems
- Choose arbitrary two individuals from these subsystems
- Make migration.
- Evaluate fitness function with these new individuals
- Save the best cost
-

- The final solution U_{best}^{Global} is found out after reactive power planning procedure to adjust the reactive power generation limits, and voltage deviation, the final optimal cost is modified to compensate the reactive constraints violations. Fig 7 illustrates the basic steps of the proposed approach.

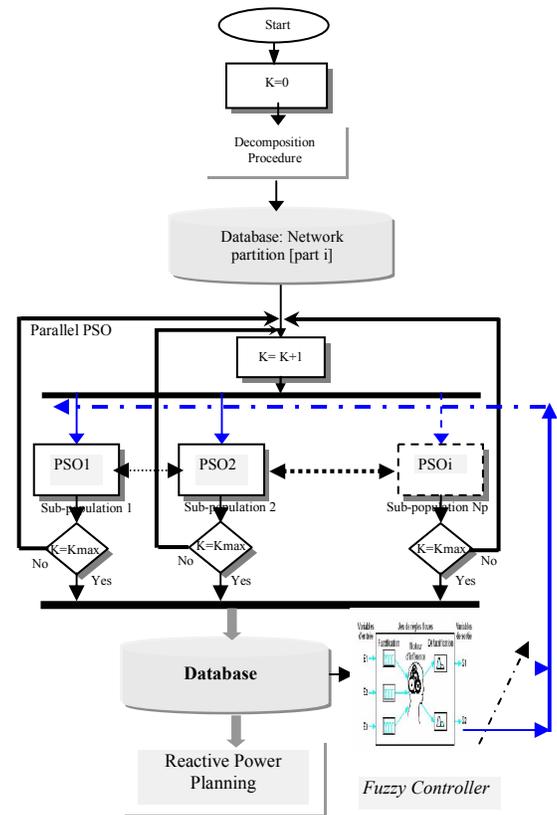


Fig 7 Procedure of parallel swarm optimization approach for EPD.

V. APPLICATION STUDY

The proposed algorithm is developed in the Matlab programming language using 6.5 version. The proposed approach has been tested on a large electrical network test 40 generating units with consideration of valve point effect.

A. Test System 1

In this application power system has 40-generating units. Total load demand of the system is 10500 MW. This is a larger system, the number of local optima, complexity and nonlinearity to the solution procedure is enormously increased. The system data can be retrieved from [5]. The final fuel cost and output power for all generating units were summarized in Table I.

TABLE I
ECONOMIC DISPATCH RESULTS FOR 40-GENERATING Units using the
PROPOSED APPROACH: PD =10500 MW

Unit N°	P_{min} (MW)	P_{max} (MW)	Pg_i (MW)	Unit N°	P_{min} (MW)	P_{max} (MW)	Pg_i (MW)
1	36	114	110.7957	21	254	550	523.2753
2	36	114	110.8120	22	254	550	523.2753
3	60	120	97.3958	23	254	550	523.2770

Unit N°	P_{\min} (MW)	P_{\max} (MW)	Pg_i (MW)	Unit N°	P_{\min} (MW)	P_{\max} (MW)	Pg_i (MW)
4	80	190	179.7290	24	254	550	523.2753
5	47	97	87.7917	25	254	550	523.2915
6	68	140	139.9959	26	254	550	523.2915
7	110	300	259.5956	27	10	150	10.0000
8	135	300	284.5956	28	10	150	10.0000
9	135	300	284.5956	29	10	150	10.0000
10	130	300	130.0000	30	47	97	87.8121
11	94	375	94.0000	31	60	190	189.9959
12	94	375	94.0121	32	60	190	190.0000
13	125	500	214.7557	33	60	190	190.0000
14	125	500	394.2753	34	90	200	164.7957
15	125	500	394.2753	35	90	200	194.4056
16	125	500	394.2753	36	90	200	200.0000
17	220	500	489.2753	37	25	110	110.0000
18	220	500	489.2753	38	25	110	109.9959
19	242	550	511.2915	39	25	110	110.0000
20	242	550	511.2753	40	242	550	511.2915
Total power output (MW)							10,500
Total generation cost (\$/h)							121414.18337

VI. DISCUSSIONS

A. Solution Quality

Observing the comparison results depicted in Table II, the proposed hybrid approach is shown to be more efficient than the other global optimization methods. Details results will be given in the next full paper.

B. Computational Efficiency

Computational efficiency analysis is an important index to test and validate the robustness of an algorithm. The mean CPU time to converge to the best solution have been observed and shown in Table II. The proposed approach takes an average CPU time of 8.54s to find the best near global solution. Fig 8 shows clearly the performance of the convergence characteristic curve of the fuzzy controlled PSO based decomposed procedure for one partition.

TABLE II
COMPARISON OF EPGA WITH OTHER GLOBAL OPTIMIZATION METHODS
40-GENERATING UNITS PD=10500 MW

Methods	Minimum Cost(\$/h)	Average CPU time (s)
*		
ICA-PSO [2]	121413.200	139.9200
SA-PSO [2]	121430.000	-

SOH-PSO[2]	121501.140	-
DE[2]	121416.290	-
MPSO [2]	122252.260	-
PSO-SQP [2]	122094.670	-
CDEMD [9]	121423.4013	44.3
FAPSO-NM[3]	121418.3	40
NPSO[3]	121704.74	-
SOH-PSO[3]	121501.14	-
FAPSO[3]	121712.4	87-
DEC-SQP[3]	121741.97	-
Our Approach	121414.18337	8.54

*. Infeasible solution (the actual generation cost is: 121422.1684 \$/h)

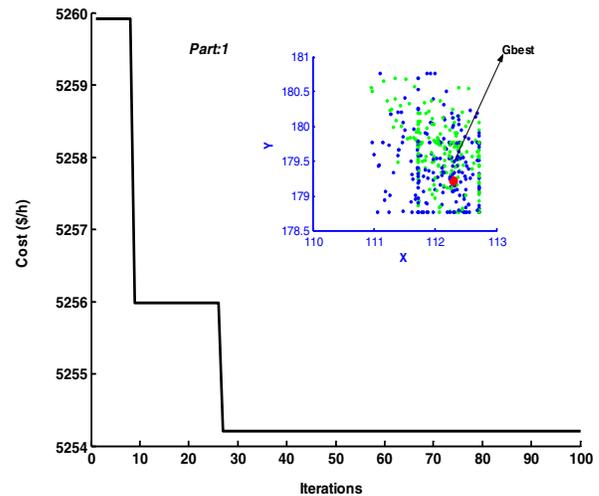


Fig 8 Convergence characteristic of 40-generator system (with valve point loading) for the first partition-Part1 (4 generating units).

VII. CONCLUSION

Application of an improved fuzzy controlled parallel PSO based decomposed network to enhance the economic dispatch for large power system with consideration of non-smooth fuel cost functions is demonstrated in this paper. In the first stage a practical rules formulated within fuzzy rules strategy designed to adjust dynamically three PSO parameters. In the second stage a decomposition mechanism is proposed to search the efficient partitioned networks to adjust the first solution found. A parallel execution of the adapted PSO associated to each decomposed search space.

The performance of the proposed approach was tested with large test system (40-generating units) with consideration of valve point effect, the results of the proposed algorithm compared with recent global optimization methods. It is observed that the proposed approach is capable of finding the near global solution of non-linear and non-differentiable objective functions and obtain a competitive solution at a reduced time.

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