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Considering Practical Constraint's Effect in Power Station Problems for Optimizing Power Generation by Comparison NSGA-II and Nested PSO

Murtaza FARSADI[1], Hadi HOSSEINNEJAD[2] and Tohid Sattarpour DIZAJI[1]

[1] Electrical Engineering Department, Urmia University, Urmia, Iran
[2] Department of Electrical Power Engineering, Urmia Branch, Islamic Azad University, Urmia, Iran
m.farsadi@urmia.ac.ir, h.hosseinnejad@iaurmia.ac.ir*, t.sattarpour@urmia.ac.ir

Abstract: *After solving problems like Unit Commitment and Economic Dispatch, it is important to consider some special constraint which come directly from nature of generators. These constraints which will mention are some related to temperate limits and other are related to dynamic of turbines. In this paper after solving the unit commitment problem and economic dispatch simultaneously, the main effect of this constraints and method for skip them will be tried. In the next part the main cost function will be detailed this kind of functions on problems which consider two cost function instead of one. The main algorithm that would be used in this paper is nested PSO. The nested PSO can optimize two functions which one of them is in the inner layer of other one.The second algorithm which would be tried the results is NSGA-II.*

Keywords: *nested PSO, constraints, Power system, NSGA-II.*

1. Introduction

Finding the right plants to connect each other for reduceing the cost is the main goal of each Unit Commitment (UC) and Economic Dispatch (ED) problem. ED or UC's usege is the first action then it's important to know the forbidden zones and other constraints like up-ramp and down-ramp. Earlier efforts on solving ED problems have employed several optimization methods. These methods are lambda iteration method, the base point method, and the gradient method etc [1]–[3].

The used method in this paper for solving these two problems together is Non-dominated Genetic Algorithm version II (NSGA-II) and nested Particle Swarm Optimization (NPSO). Nested PSO is a sub-group of Particle Swarm Optimization (PSO), which solve two or more problem in sametime, and NSGA-II is multi-objective algorithm for solving the double functions.

The main goal in UC is finding out the type of plants that must use to most efficiency and find participating amount of power as answer. In the past efforts for solving this problem, some kind of methods used including lambda-iteration, gradient method and using evolutionary algorithms [4]–[7].

Genetic Algorithm (GA), PSO and dynamic programming are most-used methods in the past efforts [8]–[12]. An optimization method known as GA that is a kind of probabilistic heuristic algorithms is using methods inspired by natural manner, such as inheritance, mutation, selection, and crossover [13]. Particle swarm optimization (PSO) is other one for optimization.. PSO optimizes a problem by having a population of first accidental solutions [14]. Dynamic programming as other method is for solving a complex problem by breaking it down into a collection of simpler sub problems. It is applicable for problems to exhibiting the properties of overlapping sub problems and optimal substructure [15]. The most important thing, which must be noticed, is that each of the earlier approaches has some difficulties, i.e. the Dynamic Programming method may lastly effects on the sizes of the ED problem, therefore requiring massive computations. About the GA method which in the past have been hired successfully to solve many complicate optimization problems, it’s important to know that there are lacks in GA. i.e., where the parameters being optimized are so depend on crossover or mutation or both together, most of the time the offsprings are the same as old generation [16]. Moreover, the GA by finding a local optimum led no improvement sometimes and stuck in a special place [4], [17]. This problems can be overcome by using NSGA-II. PSO that developed by "Kennedy" and "Eberhard" is used in solving continuous nonlinear optimization problems The PSO technique can produce first-rate solutions with littler calculation and stable answers than other methods In this paper, it’s hired PSO method for optimizing the ED problem and UC problem together. The intial idea mentioned before [18] so it will extended in some aspects in this paper.

The proposed method studies the features of a generator such as up-ramp and down-ramp rate limits and prohibited operating zone which it’s seen in an actual power system operation. The feasibility of the proposed method examined on a typical network consists on some plants.

2. NSGA-II algorithm

NSGA-II as one of the algorithms which used in the current paper is a sub-algorithm of genetic algorithm. GA is an intelligent algorithm repeats the natural selection style. In such algorithm, the most eligible parentages would be luckier to stay and change their genetic-code to the coming offspring. This technique known as evolution manner which named: crossover, mutation, selection, and etc. By this techniques, the GA would be appropriate to sensibly analysis the search universe and then

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find the ideal responses. Non-dominated genetic algorithm (NSGA) is another alogorithm from the genetic algorithm's category for couple or more objective functions optimization.

The first aim is to minimize the functions as it is obvious these function can be every regular function that mentioned in equation (1):

$$\min CostFunction(x) = \{f_1(x),...,f_n(x)\}$$
$$s.t: \; m_1(x) \leq 0, \; h_1(x) = 0, \; x \subset \Re \qquad (1)$$

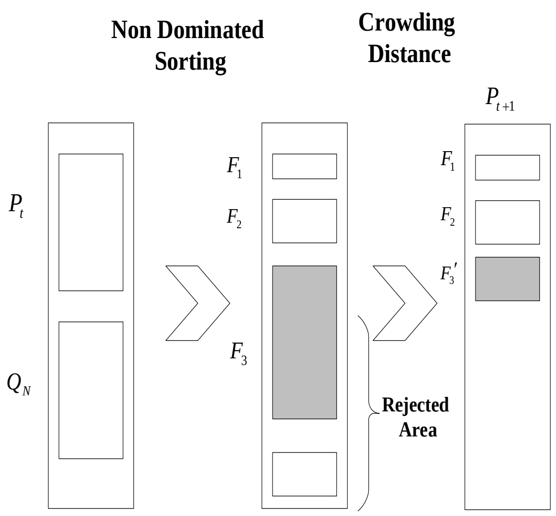


Fig. 1. NSGA-II's operating system.

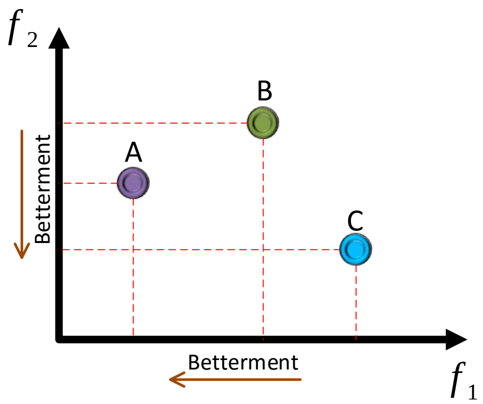


Fig. 2. A typical example of three possible answers.

The equation (1) is main function which is go to optimize as a general function, F(x) is main function that involve i parts. $f_i(x)$ shows the i-th function that is going to optimize by NSGA-II, g(x) and h(x) are restrictions that g(x) is non-equality limits and h(x) shows the equality limits. For a special goal where the function which are going to used are two, the figure.2 is the best representer.

In figure.2 particle A and particle B are better than particle C as an answer to minimization, but between particles A and B it is not obvious that which one is better, So it is important to define a concept which named “domination”. X_1 dominae X_2 means, X_2 in no feature is better than X_1. After detecting non dominating sort of answers the second action is defineing pareto front. Figure 3 shows the pareto front for an example function which is multi-objective.

The pareto front or pareto efficiency as a simple explanation can be described as a border which the answer that are on (or sometimes in) it is the best result that cannot dominate by no of the other answers. The concept is named after Vilfredo Pareto, an Italian engineer and economist who used the concept in his studies of economic efficiency .

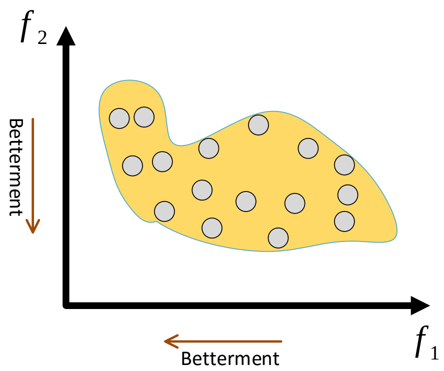


Fig. 3. pareto front for an example function.

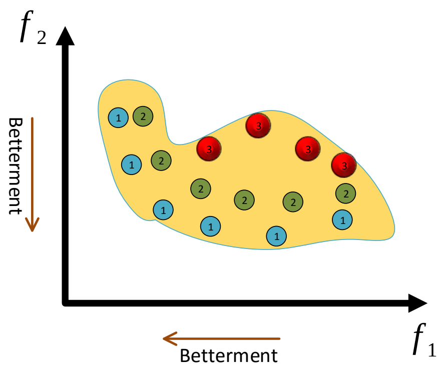


Fig. 4. Pareto front after sorting.

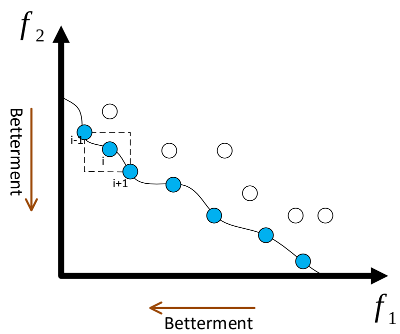


Fig. 5. Crowding distance's definition.

As it’s presented the edge round the answers is pareto front which indicated in figure 4. The following stage is defining and sorting solutions to collections (for example in 3 groups). This part is same as second part in figure 1 by dividing answers to F_1, F_2 and F_3.

The second part in figure 1 displays the limits which cut answers (F_3) and ignore some part of it as rejected part. The next step is calculating crowding distance that presented in figure 5.

$$d_j(k)=\sum_{i=1}^{n}\frac{f_i(k-1)-f_i(k+1)}{f_i^{\max}-f_i^{\min}} \qquad (2)$$

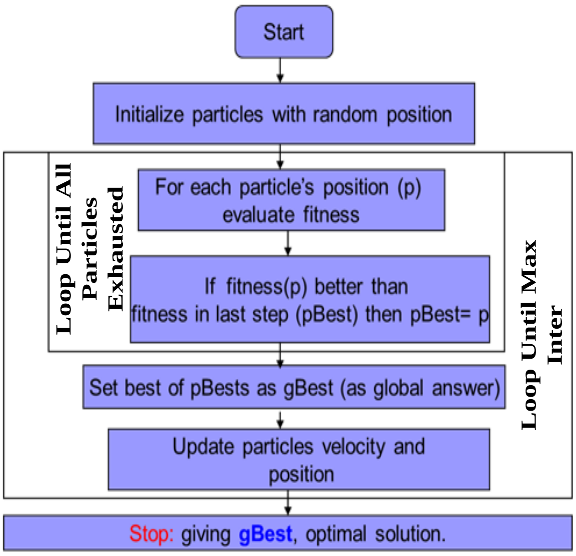
In equation 2, it is important to notice that the crowding distance distinct the best answers. An incensement of dj(k) shows the improvement of answer because of variety of answers. The last part is applying crossover and mutation on answers that give the best answers.

The NSGA-II's parameters are:

- Maximum number of iterations=200;
- Population size =50;

3. Nested PSO

Here, there is an inner and an outer PSO that work together. The benefit is that it's easy to reach two goals by considering other goal when achieving other one.



ig. 6. PSO's chart of action.

The PSO method as it described can be illustrated as chart in "Fig. 6". In this chart and it's related pseudo, 'p' is the position or first generation of PSO as a priory answer, the best solution (fitness) particle has achieved so far is showed by "pBest", and the best value obtained by any particle as global best is modeled by "gBest". It's considered P=Xk and updated position (answer) illustrated by Xk+1 .

Basic algorithm as proposed by 'Kennedy' and 'Eberhart' can present as shown in Table 1.

Usually, C_1 and C_2 considered as C_1= C_2=2 in PSO. Position of individual particles updated can described as equation (3):

$$X_{k+1}^{i}=X_{k+1}^{i}+V_{k+1}^{i} \qquad (3)$$

Table 1. Parameters definitions.

X_k^i	Particle position (current particle or solution)
V_k^i	velocity of agent *i* at iteration *k*.
P_k^i	Best "remembered" individual particle position *i*.
X_k^g	Best "remembered" swarm position
C_1,C_2	Cognitive and social parameters (learning factors)
r_1,r_2	Random numbers between 0 and 1

The velocity can calculate as equation (4):

$$V_{k+1}^{i}=V_k^i+C_1r_1(P_k^i-X_k^i)+C_2r_2(P_k^g-X_k^i) \qquad (4)$$

By considering equation (2) that have three parts consists on inertia (V_k^i), personal influence ($C_1r_1(P_k^i-X_k^i)$) and social influence ($C_2r_2(P_k^g-X_k^i)$), it can show as the concept in "Fig. 7" The end term as it described in pseduo is while maximum iterations or minimum error criteria is not attained, which one arrive first.

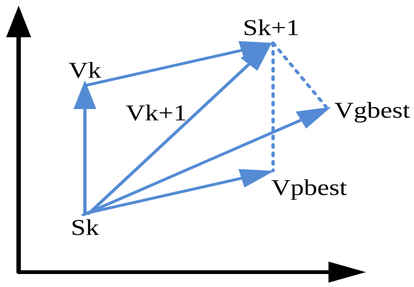


Fig. 7. Concept of modification of a searching point by PSO.

4. Problem Definition

As first step, the problem should model. The Economic Dispatch is a sub problem of the Unit Commitment, so it will define after defining UC.

As it is mentioned in UC, it should find out which kind of plants is better to use in a specific kind of plan. For this aim the following kind of plant is used as a priory choice. The plants that detailed in "Table 1" are six typical units which can change to any real model which here directley came from [1]:

Table 2. Properties of Units.

Unit	$P_{i\,(min)}$ {MW}	$P_{i\,(max)}$ {MW}	α_i {\$}	β_i {\$/MW}	γ_i {\$/MW^2}
1	100	500	240	7.0	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.5	0.0090
4	50	150	200	11.5	0.0090
5	50	200	220	10.5	0.0080
6	50	120	190	12.0	0.0075

Where α_i, β_i and γ_i are the cost equation's coefficients for the *i*-th generator in the equation (5):

$$\min F_t=\sum_{i=1}^{m}F_i(P_i)=\sum_{i=1}^{m}\alpha_i+\beta_iP_i+\lambda_iP_i^2 \qquad (5)$$

Where $P_{i\,(min)}$ and $P_{i\,(max)}$ are the constraints of plant *i* for producing power in Watt. The main Goal is optimization of equation F_t as mentioned above.

After denoting this plant because it's important to be cautious about limits of each plant, it should define some prohibited zones that cannot be an answer, and our plants cannot produce this part of power. As it is showed in "Table 3" below, for example it is 80 to 90 and 110 to 120 for unit number 4.

Table 3. Unit's limits.

Unit	P_{i0} {MW}	UR $_i$ {MW/h}	DR $_i$ {MW/h}	Prohibited Zones {MW}	Cost {$ Mil.}
1	440	80	120	[210-240], [350-380]	50
2	170	50	90	[90-110], [140-160]	35
3	200	65	100	[150-170], [210-240]	40
4	150	50	90	[80-90], [110-120]	28
5	190	50	90	[90-110], [140-150]	32
6	110	50	90	[75-85], [100-105]	22

In the "Table 3" the UR_i and DR_i are Up-Ramp limit and Down-Ramp limit of generator *i*, and P_{i0} the current output power of it, thus:

$$P_i - P_{i0} \le UR_i \tag{6}$$

$$P_{i0} - P_i \le DR_i \tag{7}$$

The cost is the other part that will consider in $ million. Now for considering prohibited operating zones, it's important to define equation (8):

$$Pi \in \begin{cases} P_i^{\min} \le P_i \le P^l_{i,1} \\ P^u_{i,j-1} \le P_i \le P^l_{i,j-1}, j = 2,3,...,nj; i = l,...,m \\ P^u_{i,n} \le P_i \le P_i^{\max} \end{cases} \tag{8}$$

As PSO is a continues algorithm, it's needed to use PSO as discontinues so equation (7) will use:

$$0 \le X \le 1 \rightarrow k = \min\{\lfloor (M+1)X \rfloor, M\} \tag{9}$$

Where $\lfloor \quad \rfloor$ is sign for integer part of equation between it, and X is produced coincidental by PSO. It's supposed in this paper that there is 6 units, So k belong to $\{0,1,2,\ldots,6\}$, and the "Unit 0" means that there is no need any unit there, with all factors that are zero or not a number in real world, this is for that the model can use the algorithm for calculation by computer.

After finding answers for UC, PSO tried again for gaining ED producing answers in each iteration. The ED planning must run the optimal generation dispatch between the operating units to satisfy the system demand and practical operation constraints.

For ED, the "Table 1" and "Table 2" used again of course without any need to cost column. It is obvious only the types are chosen that came from last step of UC's PSO. The best solution in every step will save to compare with incoming answers.

5. PSO Sturcture

As it is mentioned PSO is used in this paper as nested PSO and contain two interrelate part of a whole as it is showed in "Fig. 8".

In "Fig. 8", the internal PSO is for optimization of UC and external PSO is used for optimization of ED, that this two PSO algorithm used together at same time and external PSO use internal PSO's results online.

After describing algorithm as a whole, the next step is recognizing how to apply it to especial problem that here is ED an UC. Our algorithm's main parts are most like other evolutionary algorithms such as genetic, ant colony (a sub group of PSO), etc. For more contact between parts of algorithm it is important to first define a priory population or exactly position as mentioned it by answer in final conclusion.

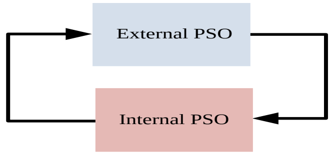


Fig. 8. The nested PSOs connection as a whole.

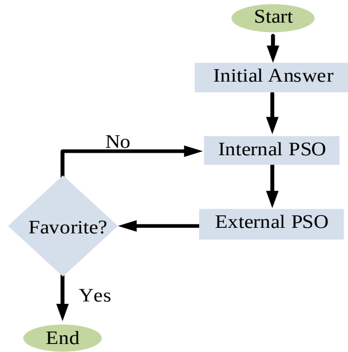


Fig. 9. Contact between internal and external PSOs.

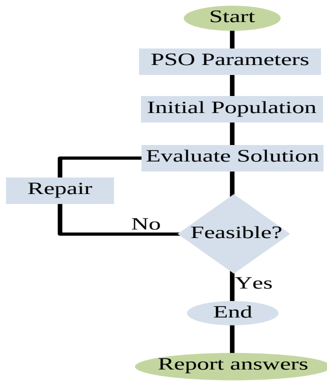


Fig. 10. Every separate PSO's structure.

The contact between internal and external PSO by applying in algorithm, is illustrated in "Fig. 9". Each PSO is however with contact with other one but it's a separate PSO algorithm that can describe with "Fig. 10".

The parameters of the used PSO for both internal and external PSO are:

- Maximum number of iterations for external PSO=10;
- Maximum number of iterations for internal PSO=100;
- Population size (Swarm Size) =10;
- Inertia weight =1;
- Inertia weight damping Ratio =0.99;
- And velocity limits are:
- Vel_{Max}= 0.1* (Var_{Max}-Var_{Min});
- Vel_{Min}= -Vel_{Max};

The end term as it referred in last part, is while maximum iterations or minimum error criteria is not attained , that it is choosed the maximum iteration which is 10, but it must be considered that every iteration of this 10 iteration fo external PSO have 100 iteration inside it for internal PSO, so there is 1000 iterations at last step.

The last iteration will call back the best answer which will mention in the next parts.

The typical system covers six thermal units, 26-buses, and 46 transmission lines [19]. The load demand is equal 1263 MW. The characteristics of the six thermal units are the same in Tables 1 and 2 in last part. As it's mentioned before, the goal is to optimize equation (10) by minimizing it:

$$\min F_t = \sum_{i=1}^{m} F_i(P_i) = \sum_{i=1}^{m} \alpha_i + \beta_i P_i + \lambda_i P_i^2 \quad (10)$$

But, the main limit has been considred in equation (9):

$$\sum_{i=1}^{m} P_i = P_D + P_L \quad (9)$$

Where, P_i is the power produced by plant *i-th*, P_D is demand power, *m* is number of units and P_L is power loss.

By considering conditions in last parts it is easy to formalize the limits as equation (10):

$$\max(P_i^{\min}, P_i^0 - DR_i) \le P_i \le \min(P_i^{\max}, P_i^0 + UR_i) \quad (10)$$

Where, P_i and other factors mentioned in last section. The UR_i and DR_i are Up-Ramp limit and Down-Ramp limit of generator *i*, and P_{i0} is the current output power of it and P_i is the power produced by plant *i*. The up-ramp and down ramp limits effect shown in "Fig. 11".

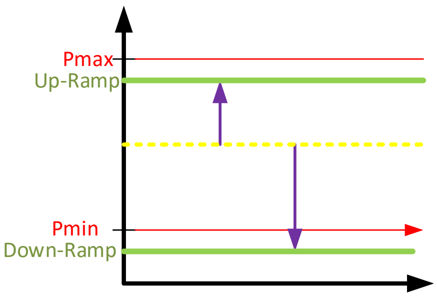


Fig. 11. Final results for UC.

As it's mentioned P_L is power loss, P_L is equal to:

$$P_L = \sum_{i=1}^{m}\sum_{j=1}^{m} P_i B_{ij} P_j + \sum_{i=1}^{m} B_{0i} P_i + B_{00} \quad (11)$$

Where, *m* is the number of generators committed to the operating system and *Pi* is the power output of the *i-th* generator. In normal operation of the system, the loss coefficients can describe with matrix *B* as follows. The matrix *B*, B_O and B_{OO} directly come from [18] which detailed all this matrixs, these kind of matrixs basicly are depand on the network which work on that system.

B_O and B_{OO} are constant, but *Bij* is a matrix which depends on network buses.

The matrix *B*, B_O and B_{OO} respectly are:

$$B_{ij} = 10^{-3} * \begin{bmatrix} 0.0425 & 0.0300 & 0.0175 & -0.0025 & -0.0125 & -0.0050 \\ 0.0300 & 0.0350 & 0.0225 & 0.0025 & -0.0150 & -0.0025 \\ 0.0175 & 0.0225 & 0.0775 & 0.0000 & -0.0250 & -0.0150 \\ -0.0025 & 0.0025 & 0.0000 & 0.0600 & -0.0150 & -0.0200 \\ -0.0125 & -0.0150 & -0.0250 & -0.0150 & -0.3225 & -0.0050 \\ -0.0050 & -0.0025 & -0.0150 & -0.0050 & -0.0050 & 0.3750 \end{bmatrix}$$

$$B_{0i} = 10^{-3} * [-0.3908 \quad -0.1279 \quad 0.7047 \quad 0.0591 \quad 0.2161 \quad -0.6635]$$
$$B_{00} = 0.056$$

There is two costs function for each seprate PSO that use together for solve problem. Cost function in algorithm is just like the equation that mentioned , but here the cost consist of all the plants cost together by put each unit's P_i in equation (12). The last answers must minimize this function.

$$F_t = \sum_{i=1}^{m} F_i(P_i) = \sum_{i=1}^{m} \alpha_i + \beta_i P_i + \lambda_i P_i^2 \quad (12)$$

6. Results

After running program and 10 iteration for main PSO and 100 for inner PSO, the best solution after 1000 iterations, showed in "Fig. 13".

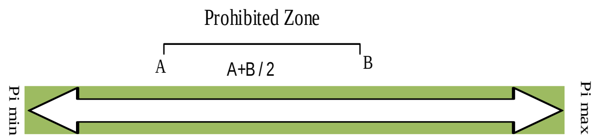


Fig. 12. Prohibited zones applying on algorithm.

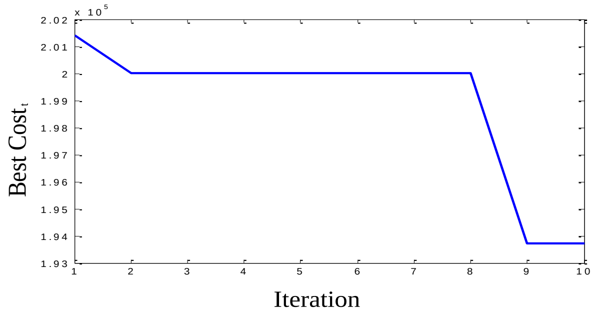


Fig. 13. External iteration for optimizing cost.

The important notice is that the "Fig. 13" shows just the best solutions answer and the total decrease in cost will appear in "Fig. 15". Here, it should consider that the 10 iteration as external iteration are only visible iterations but every iteration consist on 100 other internal iteration.

The main decrease of cost in the method which based on best knowledge of us can compared whith the results in [1], which the cost with all of the effort to hire a vrious of algorithm in [1] caused results which seems they are less than the results which will appear in this study, but it should considered that the answers in this study are more practical which consist of termo-constraint of genrators which are forbidden, unit commitment which ignored in [1] and other important noticable problems which include statrting cost of a unit that assumed a special and high cost in $ Million in this study that was not mentioned in [1].

The other refrences like [2],[4] just considered economic dispatch and [6],[11] just menctioned unit commitment as main problem whiles the both unit commitment and economic dispatch with all practical constriant, used in this study.

The NSGA-II's cost reduction curve is presented in "Fig.16". So it is obvious that the using Nested-PSO is better than NSGA-II, So the results which will report is just N-PSO's result. These results are:

- In iteration 10; best cost = 193721.2063$ Million.

The best cost after 10 iteraion, optimaized to 193721.20 $ Million and the type of plant are:

- k: [0,4,4,1,6,1]
- F: [0,28000,28000,50000,22000,50000]
- FTotal: 178000

- z: 193721

Where, *k* is type of best plants for use in this plan, that are two of 4, two of 1 and a 6 or brifly {1,1,4,4,6} which illustrated in "Fig. 13 ".

Here, *F* shows the cost of each plant that the whole cost will be 178000 $ Million, and the rest of it is ED's cost. So ED's cost will be 193721.20-178000=15721.2 $ Million.

The ED costs and BestSol will be:

- P: [0,149.3663,150,499.6838,120,418.9521]
- PTotal: 1338
- CTotoal: 15721
- PL: 74.9602
- PowerBalanceViolation: 0
- z: 15721.20
- TotalCost: 193721

Where, *P* is amount of produced power by each plant, "Ptotal" is total *P* that is needed, *PL* is power loss, and *z* is amount of ED's cost that added to UC's cost and TotalCost is 193721.20 $ Million.

PowerBalanceViolation is an consept to show how our answers are near to favarate ones.

$$P_{Total} \geq P_D + P_L \rightarrow Violation = 0 \quad (13)$$

$$P_{Total} < P_D + P_L \rightarrow Violation > 0 \quad (14)$$

By considering equation (13), it should always check that the function get the point for equation (9) or not.

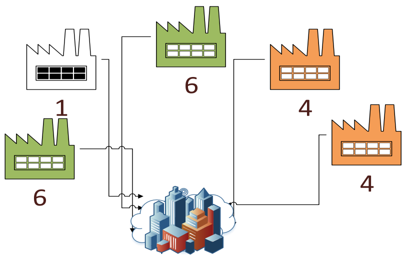


Fig. 14. Final results for UC.

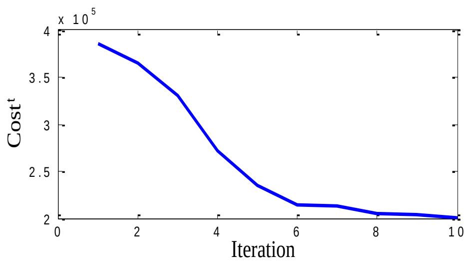


Fig. 15. PSO Iteration's effect on cost.

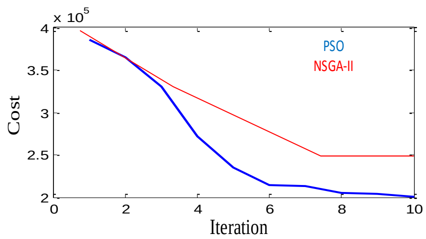


Fig. 16.PSO and NSGA-II Iteration's effect on cost.

For having this in programming, it's necessary to use equation (15) in below:

$$Violation = \max(1 - \frac{P_{Total} - P_L}{P_D}, 0) \quad (15)$$

The aim is to reduce violation to zero, or near to it, that in this paper it neared to zero. The best solution's line is thicker than other's line.

The "Fig.14" shows the cost reduction as all of the iterations where each iteration shows 100 iterations in it.

7. Conclusion

By comparison between N-PSO and NSGA-II's curve it's obvious that using two PSO as nested and together is the best choice, and it is possible to get the answers more quickly and more feasible. In this method, which it's used both of ED and UC in a nested algorithm, when it is decided to find an answer to one, the other one examine it. The most important notice is that this method is rarely depend on the plants prohibited zones so the convergence is better than other algorithms. In other aspect, it can reduce the cost, as it showed, to get the best answer at last by most efficiency. Having all kind of cost such as cost for ED and UC separately and even cost for each plant's power produce and construction is other subject that was important as it is showed. Reducing cost, gathering all constraints together, applying all prohibited zones, and etc are the most important advantages of N-PSO.

8. References

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Murtaza Farsadi received the B.Sc. degree from the METU , in 1982 and the M.Sc. and Ph.D. degrees from University of METU, in 1984 and 1989, respectively, all in electrical engineering. He is currently an Associate Professor with the School of Electrical and Computer Engineering, Urmia University, Urmia, Iran. His research interests are primarily centered in advanced power electronics and FACTS applications in power systems.

Hadi Hosseineajd received the B.Sc. degrees in electrical engineering from Urmia University, Urmia, Iran and M.Sc. (Hons.) from Islamic Azad University, Urmia Branch, Urmia, Iran, in 2013 and 2015 respectively. Currently, he is a Ph.D. candidate in power electrical engineering in the IAURMIA. His research interests are centered in smart grid technologies, electrical vehicles, optimal operation, multi objective optimization.

Tohid Sattarpur received the B.Sc. and M.Sc. (Hons.) degrees in electrical engineering from Urmia University, Urmia, Iran, in 2012 and 2014, respectively. Currently, he is a Ph.D. student in electrical engineering in the same university. His research interests are centered in smart grid technologies, optimal operation and planning of active distribution networks.