An Efficient Constraint Handling Approach for Economic Load Dispatch Problem with Non-smooth Cost Function

M.N. Abdullah[1, a *], A.H.A. Bakar[2,b *], H. Mokhlis[3,c] and J.J Jamian[4,d]

[1]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400, Batu Pahat, Johor, Malaysia.

[2]University of Malaya Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4 Wisma R&D UM, Jalan Pantai Baharu, 59990 Kuala Lumpur, Malaysia.

[3] Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.

[4]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.

[a]mnoor@uthm.edu.my, [b]a.halim@um.edu.my, [c]hazli@um.edu.my, [d]jasrul@fke.utm.my

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Abstract. Increasing of the power demand and fuel cost in power generation required an advanced algorithm for scheduling the output of generating unit in economical manner. The economic load dispatch problem (ELD) problem consists several operational and system constraints such as prohibited operating zones (POZs) and ramp-rate limit need to handle wisely by optimization algorithm. Previously, the penalty function is widely used to satisfy the power balance and other constraints by augmenting the objective function with the penalized function. However, it required a proper penalty factor tuning and depends on the size of problem. This paper proposes an efficient constraint handling based on the repairing or adjusting infeasible solution into feasible solution in every iterative process. The simulation results show that the proposed constraints handling approach is better than penalty function approach in term of convergence characteristic and robustness.

Introduction

The economic load dispatch (ELD) problem is one of the important optimization problems in power system planning and operation. The system operators required to distribute the total power demand to the scheduled unit in economically. The aim of ELD problem is to optimize the total cost of power generation and also fulfilling the system and operational limits. The ELD problem become non-convex and non-smooth optimization problem when prohibited operating zones, valve point effect, ramp-rate limit and transmission losses are considered [1, 2].

Many optimization algorithms have been implemented to tackle the ELD problem which can be categorized into conventional and meta-heuristic method. The conventional method such lambda iteration method, linear programming gradient method are limited to the nature of cost function. Currently, the meta-heuristics algorithm such as genetic algorithm [3], evolutionary programming [4], particle swarm optimization [5], artificial bee colony [2], cuckoo search [6] and hybrid methods [7, 8] are widely used to solve the ELD problem and promises a good solution. This is due to their capability for obtaining a global or near to global solution regardless the convexity and complexity of the problem.

However, most of the optimization method are utilized the penalty function approach [9, 10] for handling the constraints in ELD problem. The simple implementation is the advantages of this approach where the constraints are combined with the objective function. The penalty factor is utilized to penalize the solution that violated the constraints. As a results, a proper penalty factor tuning are required to ensure that all solution is satisfied the considered constraints. It also highly depends on the size of problem as well as number of constraints. Considering the non-smooth cost function due to POZs in ELD problem makes the difficulty for the optimization algorithm to satisfy power balance as well as generator constraints. Therefore, this paper proposed a constraint handling techniques without penalty factor tuning and capable to accelerate the convergence behaviour of the optimization algorithm for solving ELD problem with non-smooth cost function.

ELD with Non-Smooth Cost Function

The ELD problem is about the determining of real power output of the scheduled unit at lower cost while fulfilled all the system and operational limits. Considering the POZs, the ELD problem becomes non-smooth cost function as shown in Fig. 1. The cost characteristic of the *i*th generator is presented as quadratic function as follows:

$$F_C = \sum_{i=1}^{Ng} F_{C_i}(P_i) = \sum_{i=1}^{Ng} (a_i P_i^2 + b_i P_i + c_i) \qquad i = 1,2,\ldots Ng \tag{1}$$

where, F_C is the total fuel cost, F_{Ci} is the fuel cost for the *i*th generator, P_i is the real power output of *i*th generator (MW), a_i, b_i and c_i are the fuel cost coefficients of the *i*th generator and Ng is the number of generating unit.

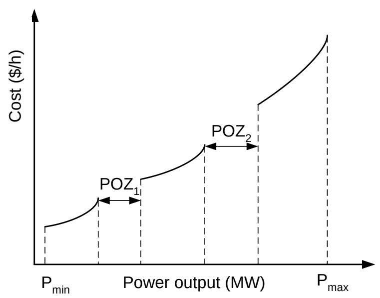

Fig. 1: Cost function with prohibited operating zones.

The generated power by each generating unit must be satisfied the power demand and system constraints as follows:

i) Power demand and transmission losses

The total real power output must be fulfilled to the predicted total power demand (P_D) and transmission losses (P_L) as follows:

$$\sum_{i=1}^{Ng} P_i = P_D + P_L \tag{2}$$

$$P_L = \sum_{i=1}^{Ng}\sum_{j=1}^{Ng} P_i B_{ij} P_j + \sum_{i=1}^{Ng} B_{i0} P_i + B_{00} \tag{3}$$

where, P_D B_{ij}, B_{i0} and B_{00} are the *B*-loss coefficients matrix.

ii) Generation and ramp-rate limits

For stable operation, the generated power output of each unit should be within the generation and ramp-rate limits as follows [2]:

$$\max\ (P_i^{\min}, P_i^0 - DR_i) \le P_i \le \min\ (P_i^{\max}, P_i^0 + UR_i) \tag{4}$$

where, P_i^{min} and P_i^{max} are the lower and upper limits, P_i^0 is the previous real power output (MW), DR_i and UR_i are the lower and upper ramp rate limits of *i*th generator (MW/h) respectively.

iii) Prohibited operating zones

Due to the vibration in shaft bearing or other machine components, the *i*th generator output must be avoided in these zones [2]. Therefore, the cost characteristic in (1) becomes discontinuous and non-smooth due to POZs as follows:

$$P_i \in \begin{cases} P_i^{\min} \le P_i \le P_{i,1}^{LB} \\ P_{i,z-1}^{UB} \le P_i \le P_{i,z}^{LB} \\ P_{i,Nz}^{UB} \le P_i \le P_i^{\max} \end{cases} \qquad z=2,3\ldots,Nz \qquad (5)$$

$P_{i,z}{}^{LB}$ and $P_{i,z}{}^{UB}$ are the lower and upper limits of *z*th POZs in (MW) respectively and *Nz* is the number of POZs of *i*th generator.

Proposed Constraint Handling for non-smooth ELD Problem

Commonly, the penalty function is widely implemented for handling the constraints in the power dispatch problem. In this approach, the constraints in (2) to (5) are combined with the objective function to form by penalized the infeasible solution [9, 11]. This required an appropriate penalty factor in order to ensure that the solution satisfy all the given constraints sufficiently.

In this paper, a constraints handling based on repairing the infeasible solution are proposed to ensure that all the generated solution during optimization process are satisfied as shown in Fig. 2.

Input: updated particle (P_i), total power demand (P_D), *B*-loss coefficients Matrix, Initial power output (P^0), ramp-rate limit (*DR*, *UR*), prohibited operating zones (POZs)
Output: Feasible updated particle (P_i)

Begin (Constraints handling)
Step 1: Calculate transmission loss (P_L) using (3) and power balance error (ΔP) using $\Delta P=P_D-\sum(P_i)-P_L$
Step 2 Randomly choose the *k* generator number between 1 and N_g
k = fix($rand*d$+1)
Step3 ***While*** (the $|\Delta P| < \varepsilon$; ε is very small positive number)
Set $P(i,k) = P(i,k) + \Delta P$.
Check the effective power limit according to (4)
If ($P(i,k) > min\ (P_i^{max}, P_i^0 + UR_i)$)
$P(i,k) = min\ (P_i^{max}, P_i^0 + UR_i)$
end

If ($P(i,k) < max\ (P_i^{min}, P_i^0 - DR_i)$)
$P(i,k) = max(P_i^{min}, P_i^0 - DR_i)$
end
Check the prohibited operating zones limit (POZs) according to (5)
For (every *z*th POZs in *i*th generator)
Calculate the average value of the zth POZs ($P_{i,z}{}^{mean}$)
If ($P(i,k) > P_{i,z}{}^{mean}$)
$P(i,k) = P_{i,z}{}^{UB}$
end
If ($P(i,k) < P_{i,z}{}^{mean}$)
$P(i,k) = P_{i,z}{}^{LB}$
end
end for
Calculate transmission loss (P_L) using (3) and ΔP
Choose another *k* number of generator (without repeat its own number)
End While
End (Constraints handling)

Fig. 2: Proposed constraint handling based on adjusting infeasible solution.

If the solution violated the constraints in (2) to (5), the algorithm tries to adjust the solution to make it feasible. Thus, it can accelerate the optimization algorithm to obtain the optimal solution.

Both constraints handling approaches are implemented in the MPSO-TVAC [12] in order to investigate their performance in solving ELD problem with non-smooth cost function

Numerical Results and Discussion

The performances of the constraint handling approaches have been tested on the power system benchmark which is 15-unit test system [9]. It consists 15 generating units with ramp-rate limit and POZs. The total power demand is 2630 MW. Fig. 3 (a) shows that proposed constraints handling can accelerate the convergence of MPSO-TVAC algorithm faster than common penalty factor approach. This is due to the only feasible solutions (with satisfying all the constraints in (2) to (5)) are generated during the iterative process. Moreover, it capable to produce consistent results than penalty factor approach after 50 different trials as illustrated in Fig. 3 (b).

The optimal solution obtained by proposed algorithm shows in Table 1. It also compared with the results of existing algorithm that utilizing penalty factor approach for handling the constraints in ELD problem with non-smooth cost function. It found that the optimal cost obtained by MPSO-TVAC* (with proposed constraints handling) is lower than other others. Moreover, it capable to produce good and consistence results with smallest standard deviation (SD) and simulation time as compared to MPSO-TVAC with penalty function approach. This reveals the efficiency of the proposed method.

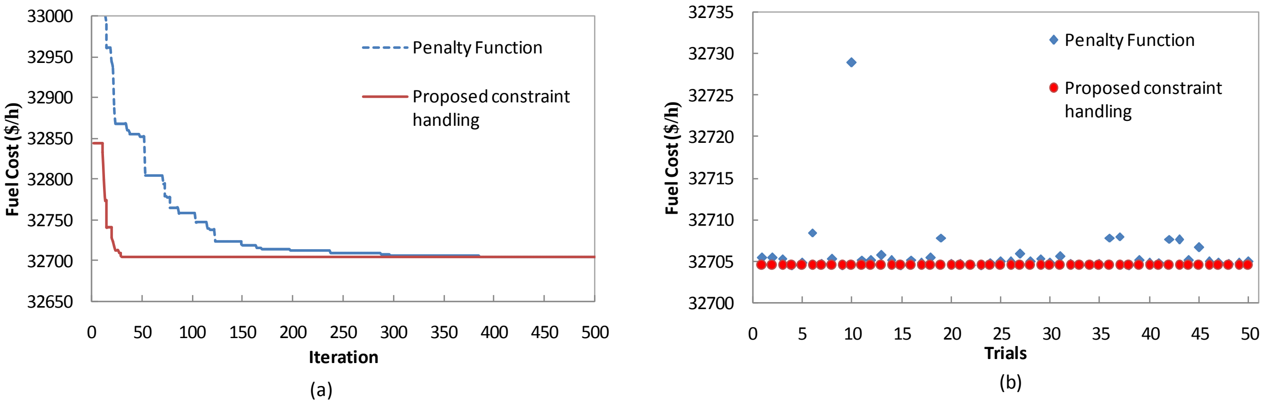

Fig. 3: (a) Convergence characteristic (b) Optimal solution after 50 trials of MPSO-TVAC with penalty function and proposed constraints handling.

Table 1: Comparison of the optimal cost obtained by various algorithms after 50 trials

Cost/Algorithm	PSO [9]	GA-API [3]	FA [13]	MPSO-TVAC	MPSO-TVAC*
Min	32858.00	32732.95	32704.50	32704.47	32704.45
Average	33039.00	32736.06	32856.10	32705.80	32704.45
Max	33331.00	32756.01	33175.00	32728.99	32704.45
SD	26.59	-	147.17	3.51	1.22E-08
Iteration				350	50
CPU time				3.96	0.65

* with proposed constraints handling

Conclusion

From this study, it should be highlighted that the constraints handling approach is also influenced the performance of optimization algorithm. The proposed constraint handling approach based on the repairing strategy for handling the power balance, POZs, ramp-rate limit and transmission losses constraints can be accelerated the convergence behaviour and reduce the simulation time efficiently.

Moreover, it found that the results obtained are more robust and consistence compared to penalty function approach. Therefore, it can be further implemented in other optimization algorithm for solving non-convex and non-smooth power dispatch problem.

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