Multi-Area Economic Dispatch by Using Differential Evolution Immunized Ant Colony Optimization (DEIANT)

N. H. Marzuki, N. A Rahmat, J. Mat Salleh, O. F. Otoh

Abstract: Economic dispatch is an important issue within the electrical system in meeting the lowest cost of the system and is subject to transmission and operating constraints.The power system operation and planning economic dispatch required a reliable technique to achieve minimal cost in economic dispatch otherwise the objective to minimize the generation cost fail. The electrical transmission network does not make complete electricity generation in Single-area economic dispatch. Thus, to complete the economic dispatch for the power transmission system, the multi-area network is proposed. The Multi-Area Economic Dispatch(MAED) connects two or more areas through a tie-line. Each region has a specific cost and load pattern. Tie-lines are used as connectors to enable power switching between regions. 31-Bus test system tested using an algorithm known as Differential Evolution Immunized Ant Colony Optimization (DEIANT) with different case studies with several trials taken to assess the consistency of results. Comparative studies with Pre-Optimization and Newton Rap son revealed that DEIANT technique is more reliable for multi-area power system network.

Keywords: Multi-Areaeconomic Dispatch, Differential Evolution Immunized Ant ColonyOptimization

I. INTRODUCTION

This document is a template. For questions on paper guidelines, please contact the conference publications committee as indicated on the conference website. Information about final paper submission is available from the conference website. The process of determining the appropriate operating costs for generation scheduling to meet the requirements of the load within a certain period is recognized as Economic Load Dispatch (ELD) [1]. Economic dispatch algorithm only considers cost that is directly associated with the generator operation, primarily the fuel cost. Economic Load Dispatch (ELD) problem involves the scheduling of electrical power generation among the generating units that can satisfy load demand at minimum operating cost [2, 3].

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Numerous efforts on solving ELD have made use of various mathematical programming and optimization techniques such as Particle Swarm Optimization [4], Artificial Bee Colony Algorithm [5], Genetic Algorithm [6], Pattern Search Algorithm [7], Neural Networks [8], Evolutionary Programming [9], and Harmony Search Algorithm [10].

The above- mentioned optimization have been tested on a single area power system and it is proven that all of these algorithms are capable of optimizing a single area ED. Multi-region ED (MAED) is a continuation of the problem arising on the ED issue [11] - [12]. ED issues need to be answered for each zone and for power exchanges between zones should be examined while each constraint is met, and achieves the primary objective of minimizing.

In addition, the constraints that need to be addressed incarrying out the MAED study are tie-line. Some mathematical methods such as linear programming [12] or taking into account the stability of the index either the strength of the bus or the power of the line to make the connection [13]. There are studies using expert systems [14] or Dantzig-Wolfe decomposition principles [15] to solve MADE problems. Multi area ED (MAED) is a developed ED problem. The main goal of MAED is togovern the power generation and the power transmission between all areas so that the objective function will be minimized, and the constraints and the load demand are fulfilled [14]-[16]. There are loads of issues that are resolved by the essential Ant Colony Optimization (ACO) methodology. After many varieties of analysis were created, sadly, Ant Colony Optimization (ACO) has some weaknesses that are the algorithmic rule become slower because of the random choice strategy of the ACO. ACO have lower convergence rate according to study conducted by R. Bhavani et al [17]. On that weakness, several processes were introduced which were clones, mutations, crossover and also elections. Modifying the basic ACO positive feedback strategy through the cloning process can reduce the number of loop calculations produced.This-cloning process is derived from the Artificial Immune Systems (AIS) algorithm. DEIANT is a combination of three techniques namely AIS, DE and ACO for a good optimization method. This method was introduced in 2016.

II. MULTI-AREA ECONOMIC DISPATCH (MAED)

MAED is a continuation of the problem arising on the ELD issue [18]. ELD issues need to be answered for each zone and for power exchanges between zones should be examined while each constraint is met, and achieves the primary objective of minimizing. In addition, the constraints that need to be addressed in carrying out the MAED study are tie-line. Some mathematical methods such as linear programming [17], [19] or taking into account the stability of index either the strength of the bus or the line power to make the connection [20]. There are studies using expert systems [21] or Dantzig-Wolfe decomposition principles [22] to solve MAED problems.

MAED is a developed ELD problem. The main goal of MAED is to govern the power generation and the power transmission between all areas so minimized the objective function, and the constraints and the load demand are fulfilled [23]. MAED is extension and expansion of normal economic dispatch. The purpose of MAED is also to obtain the lowest operating costs and meet all the constraints involved in generating power as well as transfer power between area [24], [25].

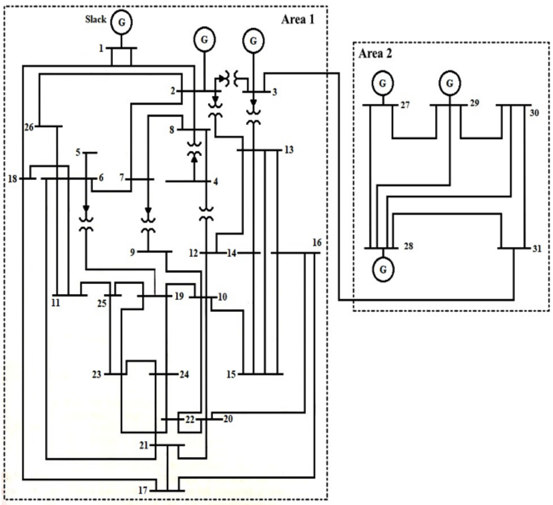


Fig. 1 One-line diagram for 31-Bus System

The main goal of this study is to ensure that the power generation level for all areas (Area 1, Area 2) takes the lowest cost and reduces power loss. Equation 1 below is used to calculate the cost of the total power system [26].

$$Ctotal = \sum_{i}^{Ng} C_i\,(P_i) \qquad (1)$$

Where:

C_{total} - the operating cost of the power system

Ng - the number of generators

$C_i(P_i)$ - the cost function

P_i - the output power of the generator unit i

The economic dispatch formula involving the cost function and the power generated from each generator for all areas has been formulated for MAED. The cost function is estimated through a quadratic function based on IEEE data. The economic dispatch equation is as shown in Equation 2 [27]:

$$C_i(P_i) = (\alpha_i P_i^2 + b_i P_i + c_i) \qquad (2)$$

Where a_i, b_i, and c_i are the cost coefficients of i^{th} generator.Equation 3 is the power balance equation for determining generator power generation. In this study, it is one of the constraints to consider[27].

$$\sum_{n}^{Ng} P_i = P_{demand} + P_{loss} \qquad (3)$$

III. DIFFERENTIAL EVOLUTION IMMUNIZEDANT COLONY OPTIMIZATION (DEIANT) TECHNIQUE

The DEIANT technique is a combination of three-optimization technique namely AIS, DE and ACO to produce a good optimization method. This method was introduced in 2016. The combination of the three-optimization technique is possible to enhance the performance of conventional Ant Colony Optimization (ACO).Several intelligence technique such as Particle Swarm Optimization, Ant Colony Optimization and DEIANT optimization techniques as reported in [28], [29], [30]used to optimized the issue on fuzzy unit commitments. From the research conducted, DEIANT optimization techniques have been verified and provide the best solution for unit commitment compared to the other two techniques.

Researchers [29]compared DEIANT with EP and ACO techniques to evaluate their performance in optimizing the Fuzzy Combined-Emission Dispatch (FCED).The study concluded that FCED problems were successfully optimized and achieved lower emission level and reduced operating cost by using DEIANT technique compared to EP and ACO.

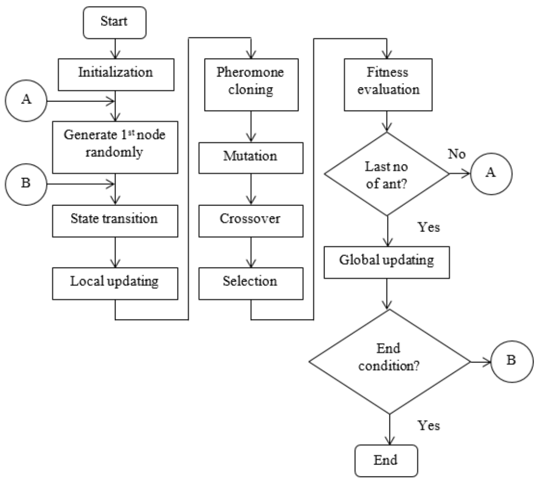


Fig. 2 DEIANT Flowchart

Initialization

The DEIANT algorithm requires important parameters such as number of ants (m), number of nodes (n), pheromone evaporation rate ($\rho\varepsilon$), ant clone factor and also crossover constants.The numbers of routes is determined by the number of ants (m) involve. Meanwhile, the large number of node (n) will take a long time to calculate. The number of ants and the number of nodes are proportional. As the number of ants increases, the number of nodes also increases and may take longer to calculate. However, having a larger number of nodes can yield greater results. In this study, the number of nodes represents the number of generators.

State Transition

The ants move from one node to another and the first node is randomly selected. The next node is determined by following the transition rule shown by Equation (4).

$$P_k(r,s) = \begin{cases} \dfrac{[\tau(r,s)] \cdot [\eta(r,s)^{\beta}]}{\sum \mu \varepsilon J_{k(r)} [\tau(r,s)] \cdot [\eta(r,u)^{\beta}]} \end{cases} \quad (4)$$

Where:

P- pheromone trail
Jk(r)- the unexplored nodes
r - current node
s - next node
η - the inverse of distance.
τ -initial pheromone level
B -pheromone layer in respect to the distance

Local Updating Rule

An ant deposits a pheromone layer as it moves from one node to another. The fastest distance will be high pheromone intensity.The pheromone level will be updated based on the evaporation coefficient (ρ) once all the ants have complete the visit. The $\rho$is to avoid premature convergence that prevents the growth of unwanted pheromones.Evaporation coefficient (ρ):0 <ρ< 1.The followinglocal update rule equations are used[29]:

$$\rho(m_n, n_n) \leftarrow (1 - \rho_e)\tau(m,n) + \rho\,(m,n) \quad (5)$$

Where:

$\rho(m_n,n_n)$ - the current pheromone level
$\rho(m,n)$ - the updated pheromone level
ρ_e - the pheromone evaporation coefficient

Pheromone Cloning

The Cloning process is a duplicate of the original pheromone layer that requires the motivation of the AIS method. In this process, the pheromone layer will be duplicated into several replicas and will undergo the next process called pheromone mutation[31].

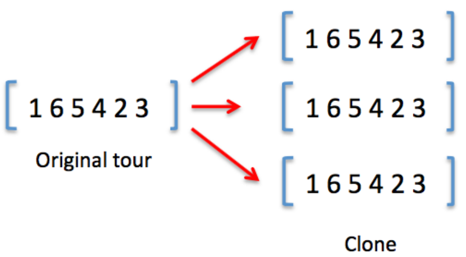


Fig. 2 Pheromone cloning process of DEIANT

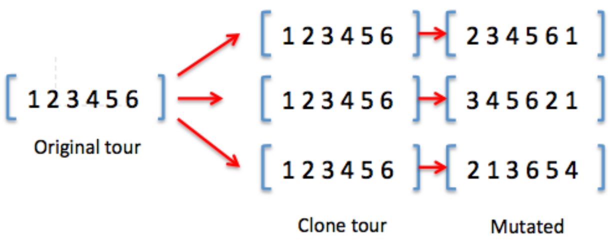
Pheromone Mutation

The mutation process is a change in the DNA sequence. To avoid early convergence in DEIANT techniques, the modified Gaussian Distribution equation was used in this investigation [32] The following pheromone mutation equations are used.

$$X_{i+m} = X_{i,j} + N\left(0, \beta\left(X_{jmax} - X_{jmin}\right)\frac{f_i}{f_{max}}\right) \quad (6)$$

Where:

X_{i+m} - Pheromone mutation function
$X_{j\,min}$ - Smallest node number
$X_{j\,max}$ - largest node number
f_i - travelled distance
f_{max} - maximum distance



Selection

Combining the parent pheromone matrix (*ρmat*), with the original pheromone matrix is called the crossover process. Pheromone offspring (*ρx*) is the result of merging and the matrix will be arranged in descending order as illustrated in the following figure.

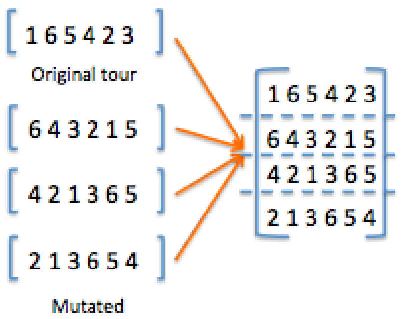


Fig. 3 Mutation and Crossover process

Control Variable

Control variables are introduced and they play a major role in the DEIANT algorithm. In this study, control variables will be treated as individual generators since each node represents each generator in MAED. Equation 7 is used to calculate the control variable x [31]:

$$x = \frac{d}{d_{max}} \cdot x_{max} \quad (7)$$

Where:

d - the distance of ant tour
d_{max} - the maximum distance
x_{max} - the maximum value of x

Global Updating Rule

The ants that provide the most accurate solution and serve as the best solution will be selected using global updating rules. The rules for global updating rules are as follows[1]:

$$\rho(m_g, n_g) \leftarrow (1 - \rho_\alpha)\rho(m,n) + \rho_\alpha . \Delta\rho\,(m.n) \qquad (8)$$

Where:

$\rho_{(mg,ng)}$ - the global pheromone trace
$\rho_{(m,n)}$ - the current pheromone trace
ρ_{α} - represents the pheromone evaporation coefficient.

Termination

The DEIANT techniques will terminate the process once the best solution is found or when the iteration number converge to a certain value.

IV. RESULT AND DISCUSSION

Test System: 31-Bus system

Case 1: Base case. The power system is operating at normal condition
Case 2: Increase Load (MW) at Bus-9 (Area 1) from 50MW to 95MW
Case 3: Decrease Load (MW) at Bus-9 (Area 1) from 50MW to 10MW

```
%          Bus Bus  Voltage Angle   ---Load---- -------Generator----- Static Mvar
%          No  code Mag.    Degree  MW     Mvar  MW  Mvar Qmin Qmax    +Qc/-Ql
busdata=[1   1    1.025   0.0     40     41     0   0     0     0      4 %Area_1
         2   2    1.020   0.0     20     15    79   0    40   250      0
         3   2    1.025   0.0     60     50   100   0    40   150      0
         4   0    1.050   0.0     55     10     0   0     0     0      0
         5   0    1.045   0.0     50     30     0   0     0     0      0
         6   0    1.00    0.0     76     29     0   0     0     0      2
         7   0    1.00    0.0      0      0     0   0     0     0      0
         8   0    1.00    0.0      0      0     0   0     0     0      0
         9   0    1.00    0.0     50     50     0   0     0     0      3
         10  0    1.00    0.0      0      0     0   0     0     0      0
         11  0    1.00    0.0     25     15     0   0     0     0    1.5
         12  0    1.00    0.0     89     48     0   0     0     0      2
         13  0    1.00    0.0     31     15     0   0     0     0      0
         14  0    1.00    0.0     24     12     0   0     0     0      0
         15  0    1.00    0.0     70     31     0   0     0     0    0.5
         16  0    1.00    0.0     55     27     0   0     0     0      0
         17  0    1.00    0.0     78     38     0   0     0     0      0
         18  0    1.00    0.0     20     67     0   0     0     0      0
         19  0    1.00    0.0     25     15     0   0     0     0      5
         20  0    1.00    0.0     40     27     0   0     0     0      0
         21  0    1.00    0.0     40     23     0   0     0     0      0
         22  0    1.00    0.0     45     22     0   0     0     0      0
         23  0    1.00    0.0     20     12     0   0     0     0      0
         24  0    1.00    0.0     50     27     0   0     0     0      0
         25  0    1.00    0.0      2     13     0   0     0     0      0
         26  0    1.015   0.0     40     20     0   0     0     0      0
         27  2    1.020   0.0     20     15    79   0    40   250      0 %Area_2
         28  2    1.045   0.0     50     10   180   0    10    50      0
         29  2    1.025   0.0     60     50   100   0    40   150      0
         30  0    1.00    0.0     30     30     0   0     0     0      0
         31  0    1.00    0.0     60     40     0   0     0     0      0];
```

Fig. 4 Bus Data for 31-System

Table.1 Generation Cost obtained During Case 1

CASE 2	Pre- Opt	Newton Raphson	DEIANT
Total Cost (RM/hr)	62,654.61	62,511.67	62,187.08

It is observed that the total generation cost for initial operating condition is 60,313.25RM/hour and the total generating cost with Newton Raphson method is60,179.81RM/hour. DEIANT Optimization gives the optimal dispatch of generation, which is 60,045.31RM/hour.

Table.2 Generation Cost Obtained During Case 2

CASE 1	Pre- Opt	Newton Rap son	DEIANT
Total Cost (RM/hr)	60,313.25	60,179.81	60,045.31

Table.3 Generation Cost Obtained During Case 3

CASE 3	Pre- Opt	Newton Raphson	DEIANT
Total Cost (RM/hr)	60,313.25	60,179.81	60,045.31

Table.4 Comparison of Power Loss Two – Area 31-Bus systems

CONDITION (MW)	CASE 1: 1185MW	CASE 2: 1225MW	CASE 3: 1145MW
Pre-Optimization	22.312	24.115	20.009
Newton Raphson	19.396	21.499	18.854
DEIANT	18.035	17.9911	16.852

The optimization results for the entire test are tabulated in Table 4.5, Table 4.6 and Table 4.7. DEIANT is the main optimization technique and is used to optimize ELD problem in terms of the operating cost and power loss. In Table 4.7, the optimization of ELD implemented on modified 26-Bus and IEEE 5-Bus system has been successfully conducted using DEIANT. By comparing DEIANT with respect to Pre-optimization and Newton Raphson, it is clearly indicated that DEIANT computed lower operating cost (60,045.31RM/hour) than Pre-optimization (60,313.25RM/hour) and Newton Raphson (60,179.81RMhour). Moreover, DEIANT has significantly optimized lower loss (18.035MW) than Pre-optimization (22.312MW), and Newton Raphson (19.396MW). The Significantly, lower P_{loss} indicates that DEIANT optimizes 4.277MW compared to initial operating condition ELD solution by balancing the amount of generated power with the load demand.

V. CONCLUSION

It can be concludedthat in ELD problem, minimizing the total operating cost is the key factor of maximizing the profitability of a generating company. The operating cost varies depending on the type of generator, facilities and equipment operated by the system. It may include the type of fuel used, generator's efficiency, and start-up cost. This dissertation was conducted on 31-Bus system. The systems contain 6-generating units respectively. The objectives are to minimize the total operating cost, to optimally dispatch generation level among the generators, and to reduce power loss. DEIANTtechnique successfully optimizes the MAED problem, this is because DEIANT is the technique that finds the shortest path and ensures that all constraints are met. Visited nodes are likened the generating units and ants are the power flow. When the ants are able to identify fastest and shortest path, the generating units do not need to generate excessive power to meet demand, thus optimized the cost and loss. This technique is also used to compare costs and power loss for Pre-Optimization and with traditional techniques, Newton Rap son. Through the DEIANT technique, the total cost of generating and losing power is reduced and yields better results.

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