# Economic Load Dispatch with Valve-Point Loading Effect by Using Differential Evolution Immunized Ant Colony Optimization Technique

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***ABSTRACT:*** *Economic load dispatch is performed by the utilities in order to determine the best generation level at the most feasible operating cost. In order to guarantee satisfying energy delivery to the consumer, a precise calculation of generation level is required. In order to achieve accurate and practical solution, several considerations such as prohibited operating zones, valve-point effect and ramp-rate limit need to be taken into account. However, these considerations cause the optimization to become complex and difficult to solve. This research focuses on the valve-point effect that causes ripple in the fuel-cost curve. This paper also proposes Differential Evolution Immunized Ant Colony Optimization (DEIANT) in solving economic load dispatch problem with valve-point effect. Comparative studies involving DEIANT, EP and ACO are conducted on IEEE 30-Bus RTS for performance assessments. Results indicate that DEIANT is superior to the other compared methods in terms of calculating lower operating cost and power loss.*

**Keywords:** Ant Colony Optimization (ACO), Differential Evolution (DE), Differential Evolution Immunized Ant Colony Optimization (DEIANT), Economic Load Dispatch (ELD)

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## 1. Introduction

Generating the correct amount of electric supply to the consumers is crucial among energy providers. By doing so, the utilities will enjoy maximized profits at a feasible operating cost and consumers will receive satisfying amount of energy. The utilities mainly use economic load dispatch to strategize their energy dispatching program [1]. Economic load dispatch (ELD) aims for producing the correct amount of energy among the available generating units to serve the load demand at the most feasible cost [2], [3] and presented as a quadratic mathematic equation. In order to feasibly generate the correct amount of electrical energy, several considerations is taken into account when solving ELD problem, including the prohibited operating zones, valve-point effect, ramp-rate limits, and emission constraints [4] – [7]. Neglecting these considerations will cause inaccurate ELD. Nonetheless, these considerations will cause ELD to become complex in terms of mathematical modelling and challenging to solve [8]. For example, prohibited operating zones will cause the fuel-cost curve to separate into several segments and form multiple decision spaces [9]. Valve-point effect will cause ripples to the fuel-cost curve and increase the non-linearity of ELD problem [10]. Ramp-rate is the rate of a generator changing its output. It requires a dynamic process of economic dispatch that varies with time and causes the curve to become non-convex curve [11], [12].

Previously, several derivatives based techniques were implemented in order to solve ELD, including lambda iteration, gradient method, Lagrangian multiplier method and dynamic programming [13]. However, some of these methods suffer dimensionality problem and long computation time is experienced when solving large system. Later on, several artificial intelligence based and heuristic techniques have been implemented into the problem such as simulated annealing [14], [15], artificial neural networks [16], evolutionary programming [17], [18], and genetic algorithm [19]. However, recent researches indicate that some of these techniques have several drawbacks. Simulated annealing (SA) is developed by Kirkpatrick, Gelatt and Vechhi [20] that was based on iterative approach. Although it can solve large and complex problem, it requires long computation time [14]. Evolutionary programming is a stochastic optimization that only produces near-optimal solution that is unsuitable for precise calculation. The algorithm also requires long computation time and have convergence problem [21].

This paper presents solving economic load dispatch with valve-point effect by using Differential Evolution Immunized Ant Colony Optimization (DEIANT) technique. DEIANT is the improvement of the original Ant Colony Optimization (ACO) algorithm by imposing mutation, crossover, selection and cloning processes from Differential Evolution (DE) and Artificial Immune (AIS) algorithm. The combination of ACO, DE and AIS aims for improving ACO in terms of computation time and prevents stagnation. Performance assessments were conducted by conducting a comparative study among DEIANT, EP and ACO. The study was conducted on the IEEE 30-Bus RTS. The study indicates that DEIANT outperforms EP and ACO in terms of computing lower operating cost and power loss.

## 2. ELD with Valve-point Loading Effect Formulation

Economic load dispatch is used to calculate the operating cost of a particular generator with respect to the generated power. ELD with valve-point effect equation is shown by equation (1):

$$C_i\,(P_i) = (a_i\,P_i^{\,2} + b_i\,P_i + c_i) + |\, d_i \sin \{e_i\,(P_{imax} - P_i)\}\,| \tag{1}$$

Where the cost function, $C_i$ is the quadratic function of cost coefficients $a_i$, $b_i$, $c_i$, $d_i$ and $e_i$ with respect to the output power, $P_i$. $P_{imax}$ is the upper limit of generator $i$. Based on equation (1), the objective of ELD is to find the total operating cost, $C_{tot}$ as in equation (2):

$$C_{Total} = \sum_{i}^{Ng} C_i\,(P_i) \tag{2}$$

The inequality constraint of each generator is presented by equation (3):

$$P_{imin} \leq P_i \leq P_{imax} \tag{3}$$

Where $P_{imin}$ and $P_{imax}$ is the lower and upper generation limit, respectively. The equality constraint or power balance equation for ELD is shown by equation (4). The equation formulates the total generation $P_{gi}$ as the summation of power demand, $P_d$ and total loss, $P_{loss}$.

$$\sum_{i}^{Ng} P_{gi} = P_D + P_{loss} \tag{4}$$

The total loss is calculated by using equation (5):

$$P_{loss} = \sum_{i}^{n}\sum_{j}^{n} P_i\,B_{ij}\,P_j + \sum_{i}^{n} B_{0i}\,P_i + B_{00} \tag{5}$$

Where $B_{ij}$, $B_{0i}$ and $B_{00}$ is the elements of loss coefficient matrix.

## 3. Differential Evolution Immunized Ant Colony Optimization Formulation

Ant Colony Optimization technique was developed by Marco Dorigo. ACO has been used in solving various problem such as the travelling salesman problem [22].

Since then, ACO has been attracting many researchers to implement it into various problems including maximum loadability in voltage control study [23], transformer tap setting [24] and optimal power flow problem [25]. However, deeper studies into the algorithm expose the fact that ACO is suffering from several disadvantages. H. B. Duan et al [26] stated that the positive feedback strategy and random selection strategy causes its algorithm to slow down and stagnate. In [27], the researcher stated that ACO was discovered to have slow convergence rate. Therefore, in order to overcome ACO drawbacks, a hybrid technique of ACO, DE and AIS is developed by combining several processes from DE and AIS including mutation, crossover, selection and cloning [28], [29] into ACO algorithm. DEIANT process is shown in Figure 1. The process is briefly discussed as follows:

### 3.1 Initialization

All parameters included in ACO namely the number of ants, number of nodes, pheromone decay factor, cloning factor, pheromone mutation factor, and crossover constant are initialized in this stage. The population number is heuristically set. Most of the parameters are adopted from ACO and DE.

### 3.2 Transition Rule

Ant will go for a random tour among the given node, ultimately creating a path between its nest and food source. The next node is selected based on the transition rule. Equation (6) presents the transition rule equation:

$$P_k(r,s) = \left\{ \frac{[\tau(r,s)]\,.\,[\eta(r,s)^{\beta}]}{\sum \mu\, \varepsilon\, J_{k(r)}\,[\tau(r,s)]\,.\,[\eta(r,s)^{\beta}]} \right. \tag{6}$$

Where:

$r$ : *Current node*

$s$ : *Next node*

$u$ : *Unvisited node*

### 3.3 Local Updating Rule

A thin layer of pheromone trace is added to the path as the ant move from one node to another. The most favoured path will have its pheromone layer gradually increased. The pheromone level is varied according to the evaporation coefficient; $\rho$. Evaporation coefficient is set between 0 and 1. Equation (7) presents the local updating rule equation.

$$\rho(m_n, n_n) \leftarrow (1-\rho_e)\,\tau(m,n) + \rho(m,n) \tag{7}$$

Where:

$\rho(m, n)$ : *current pheromone level*

$\rho(m_n, n_n)$ : *Updated pheromone level*

$\rho_e$ : *Pheromone evaporation rate*

### 3.4 Pheromone Cloning

The cloning process is adopted from the Artificial Immune System (AIS) algorithm in order to duplicate the original pheromone matrix. The original and the duplication matrix will proceed to the mutation process.

### 3.5 Pheromone Mutation

The Gaussian distribution function is the base of pheromone mutation equation. Pheromone matrix will be subjected to the mutation process. The mutated Gaussian distribution equation was shown by equation (8) as follow:

$$X_{i+m} = X_{i,j} + N\left(0, \beta\,(X_{jmax} - X_{jmin}).\,\frac{f_i}{f_{max}}\right) \tag{8}$$

Where

$X_{i+m}$ : Pheromone mutation function

$X_{jmin}$ : Smallest node number

$X_{jmax}$ : Largest node number

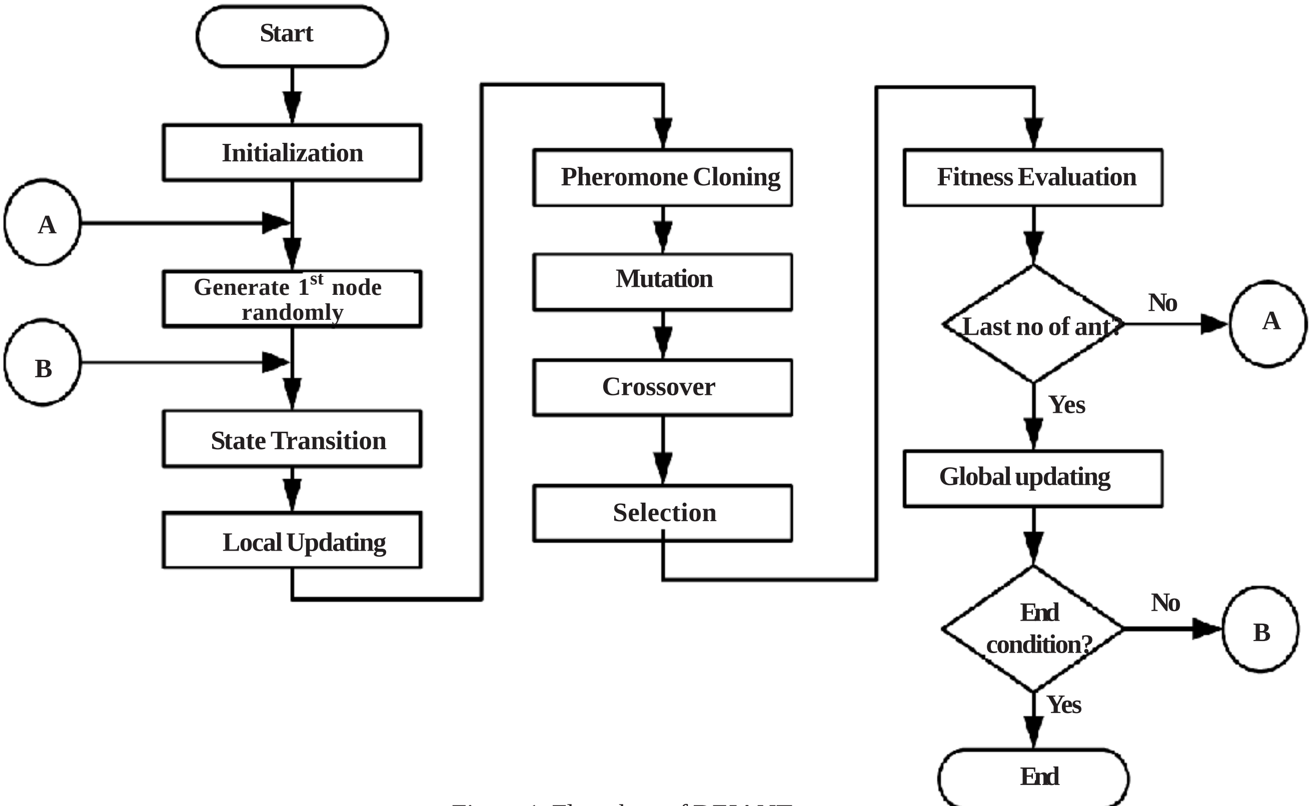


Figure 1. Flowchart of DEIANT process

$f_i$ : *Tavelled distance*

$f_{max}$ : *Maximum distance*

The Gaussian distribution function will diversify the pheromone layer by mutating the elements inside the pheromone matrix

**3.6 Crossover**

The diversification of the pheromone is determined by the crossover process that was developed based on a binomial distribution. A new matrix termed as the crossover matrix is produced by the combination of the original and the mutated pheromone matrix.

Figure 2 depicts the crossover matrix. The elements inside the matrix are sorted in a descending order.

**3.7 Selection**

R*oulette-wheel selection* technique is used as the selection technique. The selection process will pick the fittest crossover matrix. Equation (9) presents the selection process as a piecewise function:

$$\rho_{sel} = \begin{cases} \rho_{sel} \ \ \textit{if, Pheromone Level, } \rho < \rho_{sel} \\ \rho \quad \textit{otherwise} \end{cases} \tag{9}$$

$$X = \begin{bmatrix} X_m \\ X_{m-1} \\ . \\ . \\ . \\ X_{m-n} \end{bmatrix}$$

Figure 2. Crossover matrix descending order

### 3.7 Control Variable

Equation (10) is used to calculate the control variable, $x$ [23]:

$$x = \frac{d}{d_{max}} \cdot x_{max} \tag{10}$$

where:

$d$ : Distance of ant tour

$d_{max}$ : Maximum distance

$x_{max}$ : Maximum value of $x$

### 3.8 Global Updating Rule

The global updating rule will determine the best solution. The ant that carries the fittest solution will be selected and its first node will be assigned as the first node for the next tour. Equation (11) presents the global updating rule:

$$\rho\,(m_g, n_g) \leftarrow (1 - \rho_\alpha)\,\rho\,(m, n) + \rho_\alpha \,.\, \Delta\rho\,(m, n) \tag{11}$$

where:

$\rho\,(m_g, n_g)$: Global pheromone level

$\rho\,(m, n)$: Updated pheromone level

$\rho_e$: Pheromone evaporation rate

### 3.9 Termination

DEIANT algorithm terminates all its process either when it discovers the best solution or when it reaches the maximum number of iteration ($It_{max}$).

## 4. Results & Discussion

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Economic load dispatch problem with valve-point effect was implemented in MATLAB. The optimization problem was solved by the proposed Differential Evolution Immunized Ant Colony Optimization (DEIANT) technique. The research was performed on IEEE 30-Bus RTS with 6 generators. Table 1 and Table 2 tabulate the cost coefficient and generation limits for each generator, respectively. The optimization results are tabulated in Table 2:

Table 3 indicates the optimization results of ELD by using EP, ACO and DEIANT. Significant differences are observed in the ELD results before and after considering the valve-point loading effect. Based on this research, valve-point loading causes the power loss and operating cost to be higher than before. However, these results are practically more accurate as the results are considering the ripples effect on the cost curve due to the valve-point loading.

For example, by using DEIANT technique, the total operating cost for ELD is 15271.24 \$/hr. The valve-point loading causes the operating cost to escalate to 15324.69 \$/hr. The power loss increases from 1.9861 MW to 6.4136 MW. Moreover, due to the non-smooth cost curve, the optimization techniques

In terms of performance comparison, DEIANT is observed to perform the best among other techniques. Considering the ELD with valve-point loading, DEIANT computed the lower operating cost (15324.69 \$/hr) than EP (15471.33 \$/hr) and ACO (15454.68 \$/hr). According to the equation (4), in order to have lower losses, the generators are required to produce electrical power according to the demand level. Based on the comparative study, DEIANT computed a significantly lower loss (6.4136 MW) compared to EP (18.5605 MW) and ACO (17.1814 MW).

| Generator | Cost Coefficient | | | | |
|---|---|---|---|---|---|
| | $a_i$ | $b_i$ | $c_i$ | $d_i$ | $e_i$ |
| 1 | 0.152 | 38.540 | 756.80 | 0.0042 | 0.3300 |
| 2 | 0.106 | 46.160 | 451.32 | 0.0042 | 0.3300 |
| 3 | 0.028 | 40.400 | 1050.00 | 0.0068 | – 0.5455 |
| 4 | 0.035 | 38.310 | 1243.53 | 0.0068 | – 0.5455 |
| 5 | 0.021 | 36.328 | 1658.57 | 0.0046 | – 0.5112 |
| 6 | 0.018 | 38.270 | 1356.66 | 0.0046 | – 0.5112 |

Table 1. Cost Coefficient For IEEE 30-bus Rts

| Generator | GenerationLimit | |
|---|---|---|
| | $P_{min}$ $(MW)$ | $P_{max}(MW)$ |
| 1 | 10 | 125 |
| 2 | 10 | 150 |
| 3 | 35 | 225 |
| 4 | 35 | 210 |
| 5 | 130 | 325 |
| 6 | 125 | 315 |

Table 2. Generation Limit For IEEE 30-bus Rts

| Technique | | EP | | ACO | | DEIANT | |
|---|---|---|---|---|---|---|---|
| | | Without Valve-Point | With Valve-Point | Without Valve-Point | With Valve-Point | Without Valve-Point | With Valve-Point |
| Output Power (MW) | P1 | 448.0583 | 449.6265 | 447.0094 | 448.5739 | 445.4923 | 447.0515 |
| | P2 | 173.26 | 173.8664 | 172.6971 | 173.3015 | 171.4931 | 172.0933 |
| | P3 | 263.6265 | 264.5492 | 261.5588 | 262.4743 | 262.4199 | 263.3384 |
| | P4 | 138.8548 | 139.3408 | 138.3676 | 138.8519 | 135.6211 | 136.0958 |
| | P5 | 166.2653 | 166.8472 | 168.9724 | 169.5638 | 165.4634 | 166.0425 |
| | P6 | 87.02574 | 87.33033 | 87.1111 | 87.41599 | 84.4963 | 84.79204 |
| $C_{tot}$ (\$/hr) | | 15463.17 | 15471.33 | 15446.28 | 15454.68 | 15271.24 | 15324.69 |
| $P_{loss}$ (MW) | | 12.82761 | 18.56046 | 12.7164 | 17.18141 | 1.9861 | 6.413551 |
| Time (s) | | 12.3309 | 16.0923 | 10.3471 | 14.3033 | 1.2674 | 1.8347 |

Table 3. Optimization Results of Economic Load Dispatch Problem

## 5. Conclusion

This paper pointed out Differential Evolution Immunized Ant Colony Optimization (DEIANT) technique in solving economic load dispatch by considering valve-point loading effect. The valve-point loading generates ripples at the non-linear cost-curve, thus inflicting higher operating cost and power loss. Nonetheless, the solutions are practically more accurate. DEIANT is the improvement of the basic ACO technique. Comparative studies involving ELD with valve-point loading among DEIANT, ACO and EP indicates that the proposed technique is superior in terms of achieving lower operating cost and power loss.

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