



STUDY OF MULTI-AREA ECONOMIC DISPATCH ON SOFT COMPUTING TECHNIQUES

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Abstract:

This paper analyses the performance of soft computing techniques to solve single and multi area economic dispatch problems. The paper also includes of inter-area flow constraints on power system network, which are normally ignored in most economic load dispatch problems. Economic load dispatch results for these two area, three area and four area systems are presented in the paper and they determine the importance of multiple area representation of a system in economic load dispatch. Such representation affects the cost and assures the determination of optimum dispatch.

Key Words: Multi-Area Economic Dispatch, Flower Pollination Algorithm Bat Algorithm, Particle Swarm Optimization, Transmission Loss, Prohibited Zones & Multi-Fuel

1. Introduction:

Economic load dispatch [1] issue is one of the fundamental optimization problems in the industrial operation of power systems. The essential goal of the monetary dispatch issue is to determine the excellent schedule of online generating units so as to meet the power demand at least possible operating cost under various systems and operating constraints. Generally, in power system the generators are separated into many generation areas and they interconnected by utilizing tie-lines. Multi-area economic dispatch (MAED) is an development of economic dispatch. MAED decides the generation level and exchange of power between areas such that total fuel cost in all areas is curtailed while satisfying power balance constraints, generating limits constraints and tie-line capacity constraints. Romano et al. [2] Solved constrained economic dispatch of multi-area systems using the Danzig-Wolfe decomposition principle diminishes the unpredictability of the issue by isolating it into a few sub-issues. Ouyang and Shahidehpour [3] proposed heuristic multi-area unit commitment with economic dispatch with an incorporation of basic and successful tie-line imperative checking. Shoults et al [4] included power exchange limits between areas for solving the economic dispatch problem. This study gives a complete formulation of multi-area generation scheduling, and an idea for multi-area studies. Jayabarathi et al. [5] tackled multi-area economic dispatch problems with tie line constraints using evolutionary programming technique. Prasanna et al. [6] solved the Security Constrained Economic Dispatch in interconnected power system by using Fuzzy logic strategy incorporated with Evolutionary Programming and with Tabu-Search algorithms. Desell et al. [7] Applied a linear programming to transmission constrained generation production cost analysis in power system planning for a large electrical network. Wang et al. [8] Proposed a decomposition approach for the multi-area generation scheduling with tie-line constraints having non-linear characteristics using expert systems. M. Zarei et al. [9] proposed a Direct search method (DSM) is used to solve the two-area economic dispatch of the generating units with some equality and

inequality constraints with different kind of complex fuel cost function. Dan Streiffert et al. [10] proposed an Incremental Network Flow Programming algorithm for solving the multi-area economic dispatch problem with transmission constraints. P. S. Manoharan et al. [11] proposed an Evolutionary Programming with Levenberg-Marquardt Optimization technique to solve multi-area economic dispatch problems with multiple fuel options. Manoharan et al. [12] investigated the proficiency and adequacy of the various evolutionary algorithms such as the Real-coded Genetic Algorithm, Particle Swarm Optimization, Differential Evolution and Covariance Matrix Adapted Evolution Strategy on multi-area economic dispatch problems. Manisha Sharma et al. [13] compared the search ability and convergence behavior of algorithms such as Classical differential evolution (DE) and its various strategies, Classical particle swarm optimization (PSO), An improved PSO with a parameter automation strategy having time varying acceleration coefficients for solving MAED problems. Flower pollination algorithm (FPA) [14] is an optimization algorithm inspired by the pollination process of flowers. The exploration and exploitation mechanism of FPA was well suitable for the real world optimization problems. Bat algorithm (BA) [15] is an optimization algorithm based on echolocation characteristics of bats and developed by mimics of 'bats' foraging behaviour. The exploration and exploitation mechanism of BA was well suitable for the real world optimization problems. In this paper, single area and two area economic dispatch problem with inclusion of operating zones, transmission loss has been solved by using the flower pollination algorithm (FPA), Bat algorithm (BA), and particle swarm optimization (PSO). The result obtained by the techniques are compared with each other.

2. Particle Swarm Optimization:

Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behaviour of bird flocking or fish schooling. The PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called pbest), and according to the experience of a neighbouring particle (This value is called gbest), made use of the best position encountered by itself and its neighbour.

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$V_{id}^{k+1} = \omega_i V_i^k + c_1 \text{rand} * (pbest_i - S_i^k) + c_2 \text{rand} * (gbest - S_i^k) \quad (1)$$

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad (2)$$

where S^k is current searching point, S^{k+1} is modified searching point, V_k is current velocity, V_{k+1} is modified velocity of agent i , $vpbest$ is velocity based on pbest, $vgbest$ is velocity based on gbest, n is number of particles in a group, $pbest_i$ is pbest of agent i , $gbest_i$ is gbest of the group, ω_i is weight function for velocity of agent i , C_i is weight coefficients for each term. Appropriate value ranges for C_1 and C_2 are 1 to 2, ω_i is taken as 1.

2.1 Pseudo Code for PSO:

- ✓ Initialize the group (swarm size, initial velocity, particle position).
- ✓ Set the value for iteration count
- ✓ Check for fitness value of each particle

- ✓ If step 3 is satisfactory then update $pbest$ and $gbest$
- ✓ Update position and velocity
- ✓ Go to step 3 until satisfying stopping criteria otherwise go to
- ✓ When stopping criteria is satisfied.
- ✓ Print the final results.

3. Bat Algorithm:

- ✓ Each bats identify the distance between the prey and background barriers using echolocation.
- ✓ Bats fly randomly with velocity v_i at position x_i with a fixed frequency f_{min} (or Wavelength λ), varying wavelength λ (or frequency f) and loudness A_0 to search for prey. They can naturally adopt the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in [0, 1]$, depending on the closeness of their prey;
- ✓ Although the loudness of the bats can be modified in many ways, we consider that the loudness varies from a large (positive) A_0 to a minimum value A_{min} according to the problem taken.

3.1 Initialization of Bat Population:

Population initialization of bats randomly in between the lower and the upper boundary can be achieved by the equation.

$$x_{ij} = x_{min\ j} + \text{rand}(0,1)(x_{max\ j} - x_{min\ j}) \quad (3)$$

Where $i=1, 2, \dots, n$, $j=1, 2, \dots, d$, $x_{min\ j}$ and $x_{max\ j}$ are lower and upper boundaries for dimension j respectively.

3.2 Update Process of Frequency, Velocity and Solution:

The step size of the solution is controlled with the frequency factor in BA. This frequency factor is generated randomly in between the minimum and maximum frequency $[f_{min}, f_{max}]$. Velocity of a solution is proportional to frequency and new solution depends on its new velocity and it is represented as.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (4)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*)f_i \quad (5)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (6)$$

Where $\beta \in [0, 1]$ indicates randomly generated number, x^* represents current global best solutions. For local search part of algorithm (exploitation) one solution is selected among the selected best solutions and random walk is applied.

$$x_{new} = x_{old} + \epsilon A^t \quad (7)$$

Where A^t is average loudness of all bats, $\epsilon \in [0, 1]$ is random number and represents direction and intensity of random-walk.

3.3 Update Process of Loudness and Pulse Emission Rate:

As iteration increases, the loudness and pulse emission must be updated because when the bat gets closer to its prey then their loudness usually decreases and pulse emission rate also increases, the updating equation for loudness and pulse emission is given by

$$A_i^{t+1} = \alpha A_i^t \quad (8)$$

$$r_i^{t+1} = r_i^0 [1 - e^{(-\gamma t)}] \quad (9)$$

Where α and γ are constants. r_i^0 and A_i are factors which consist of random values and A_i^0 can typically be $[1, 2]$, while r_i^0 can typically be $[0, 1]$.

3.4 Pseudo Code of Bat Algorithm:

- ✓ Objective function: $f(x)$, $x=(x_1 \dots x_d)^t$
- ✓ Initialize bat population x_i and velocity v_i $i=1, 2, \dots, n$

- ✓ Define pulse frequency f_i at x_i
- ✓ Initialize pulse rate r_i and loudness A_i
- ✓ While ($t < \text{maximum number of iterations}$)
- ✓ Generate new solutions by adjusting frequency, and updating velocities and location/solutions.
- ✓ If($\text{rand} > r_i$)
- ✓ Select a solution among the best solutions
- ✓ Generate a local solution around the selected best solution
- ✓ End if
- ✓ If($\text{rand} < A_i$ and $f(x_i) < f(x^*)$)
- ✓ Accept new solutions
- ✓ Increase r_i , reduce A_i
- ✓ End if
- ✓ Ranks the bats and find current best x^*
- ✓ End while
- ✓ Display results.

4. Nature-Inspired Flower Pollination Algorithm:

4.1 Rules for Flower Pollination Algorithm:

- ✓ Biotic and cross-pollination is considered as global pollination process with pollen- carrying pollinators performing Levy flights.
- ✓ Abiotic and self-pollination are considered as local pollination.
- ✓ Flower constancy can be considered as the reproduction probability is proportional to the similarity of two flowers involved.
- ✓ Local pollination and global pollination is controlled by a switch probability $Pa \in [0, 1]$. Due to the physical proximity and other factors such as wind, local pollination can have a significant fraction pa in the overall pollination activities.

4.2 Mathematical representation of Flower Pollination Algorithm:

The first rule plus flower constancy can be represented mathematically as

$$x_i^{t+1} = X_i^t + L(X_i^t - g_*) \quad (10)$$

Where X_i^t is the pollen i or solution vector X_i at iteration t , and g_* is the current best solution found among all solutions at the current generation/iteration. Levy distribution is given by

$$L \sim \frac{\lambda \Gamma \sin(\frac{\pi \lambda}{2})}{\pi} \frac{1}{s^{1+\lambda}}, (S \gg S_0 > 0) \quad (11)$$

Where L is the strength of the pollination should be greater than zero, $\Gamma(\lambda)$ is the gamma function and this distribution is valid for large steps $s > 0$.

The local pollination can be represented as

$$x_i^{t+1} = X_i^t + \varepsilon(X_j^t - X_k^t) \quad (12)$$

Where, X_j^t and X_k^t are pollens from the different flowers of the same plant species. This essentially mimic the flower constancy in a limited neighbourhood. Mathematically, if X_j^t and X_k^t comes from the same species or selected from the same population, this become a local random walk if we draw from a uniform distribution in $[0,1]$.

4.3 Switch Probability or Proximity Probability (pa):

Most flower pollination activities can occur at both local and global scale. In practice, adjacent flower patches or flowers in the not-so-far-away neighbourhood are more likely to be pollinated by local flower pollens that those far away. For this, we use a switch probability (Rule 4) or proximity probability pa to switch between common global pollination to intensive local pollination.

4.4 Pseudo Code of Flower Pollination Algorithm:

- ✓ Objective min or max $f(x)$, $x = (x_1, x_2, \dots, x_d)$
- ✓ Initialize a population of n flowers/pollen gametes with random solutions
- ✓ Find the best solution g_* in the initial population
- ✓ Define a switch probability $Pa \in [0, 1]$.
- ✓ while($t < \text{Max Generation}$)
- ✓ for $i = 1 : n$ (all n flowers in the population)
- ✓ if $\text{rand} < pa$,
- ✓ Draw a (d -dimensional) step vector L which obeys a Levy distribution
- ✓ Global pollination via $x_i^{t+1} = X_i^t + L(X_i^t - g_*)$
- ✓ else
- ✓ Draw ϵ from a uniform distribution in $[0, 1]$
- ✓ Randomly choose j and k among all the solutions
- ✓ Do local pollination via $x_i^{t+1} = X_i^t + \epsilon(X_j^t - X_k^t)$
- ✓ end if
- ✓ Evaluate new solutions
- ✓ If new solutions are better, update them in the population
- ✓ end for
- ✓ Find the current best solution g_*
- ✓ end while.

5. Problem Formulation:

5.1. Total Cost Function:

The main objective of Economic Load Dispatch in electrical power system is to reduce the overall production cost of supplying loads while satisfying constraints. The total cost function can be formulated as the following equation.

$$F_t = \sum_{i=1}^N F_i(P_i) = \sum_{i=1}^N a_i + b_i P_i + c_i P_i^2 \quad (13)$$

Where $F_i(P_i)$ is the cost function of i_{th} generator and is usually expressed as a quadratic polynomial; a_i , b_i and c_i are the fuel cost coefficients of i_{th} generator; N is the number of generators, P_i is the real power output of i_{th} generator. The Economic Load Dispatch problem minimizes F_t subject to the following constraints and effects.

5.1.2 Equality constraints:

The power balance equation is given by

$$\sum_{i=1}^N P_i = P_D + P_L \quad (14)$$

The transmission loss P_L of system may be expressed by using B-coefficients.

$$P_{Li} = \sum_{i=1}^N \sum_{j=1}^N P_i B_{ij} P_j + \sum_{i=1}^{M_i} B_{0i} P_i + B_{00} \quad (15)$$

Where, P_D is the power demand of the system. B_{ij} , B_{0i} , and B_{00} are transmission loss coefficients.

5.1.3 Inequality Constraints:

The upper and the lower operating region of the generator is given by the equation

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad i \in N \quad (16)$$

Where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum power outputs of generator i , respectively. The maximum output power of generator is limited by thermal consideration and minimum power generation is limited by the flame instability of a boiler.

5.1.4 Prohibited Operating:

The prohibited operating zones are the range of power output of a generator where the operation causes undue vibration

of the turbine shaft bearing caused by opening or closing of the steam valve. This undue vibration might cause damage to the shaft and bearings. Normally operation is avoided in such regions. The feasible operating zones of unit can be described and represented as.

$$\begin{aligned} P_i^{\min} &\leq P_i \leq P_{i,1}^l \\ P_{i,m-1}^u &\leq P_i \leq P_{i,m}^l; \quad m = 2, 3, \dots, n_i \\ P_{i,n_i}^u &\leq P_i \leq P_i^{\max} \end{aligned} \quad (17)$$

Where m represents the number of prohibited operating zones of j th generator in area i . $P_{i,m-1}^u$ is the upper limit of $(m-1)$ th prohibited operating zone of i th generator. $P_{i,m}^l$ is the lower of m th prohibited operating zone of i th generator. Total number of prohibited operating zone of i th the generator is n_i .

5.1.5 Valve-Point Effects:

The generator cost function is obtained from a data point taken during “heat run” tests when input and output data are measured as the unit slowly varies through its operating region. Wire drawing effects, which occur as each steam admission valve in a turbine starts to open, produce a rippling effect on the unit curve. To consider the accurate cost curve of each generating unit, the valve point results in as each steam valve starts to open, the ripples like the cost function addressing valve-point loadings of generating units is accurately represented as

$$F_t = \sum_{i=1}^N F_i(P_i) = \sum_{i=1}^N a_i + b_i P_i + c_i P_i^2 + |d_i \times \sin\{e_i \times (p_i^{\min} - P_i)\}| \quad (18)$$

5.1.6 Valve-Point Effects and Multi Fuels Effect:

To obtain an accurate and practical economic dispatch solution, the realistic operation of the ELD problem should be considered both valve-point effects and multiple fuels. This project proposed an incorporated cost model, which combines the valve-point loadings and the fuel changes into one frame. as explained .

$$F_i(P_i) = \begin{cases} a_{i1} + b_{i1} P_{i1} + c_{i1} P_{i1}^2 + |d_{i1} \times \sin\{e_{i1} \times (p_{i1}^{\min} - P_{i1})\}|, & \text{for fuel 1, } p_i^{\min} \leq P_i \leq P_{i1} \\ a_{i2} + b_{i2} P_{i1} + c_{i2} P_{i2}^2 + |d_{i2} \times \sin\{e_{i2} \times (p_{i2}^{\min} - P_{i2})\}|, & \text{for fuel 2, } p_i^{\min} \leq P_i \leq P_{i2} \\ \vdots \\ a_{ik} + b_{ik} P_{ik} + c_{ik} P_{ik}^2 + |d_{ik} \times \sin\{e_{ik} \times (p_{ik}^{\min} - P_{ik})\}|, & \text{for fuel k, } p_{ik-1}^{\min} \leq P_i \leq p_i^{\max} \end{cases} \quad (19)$$

5.2 Multi- Area Economic Dispatch With Transmission Loss and Prohibited Zones:

The objective of the MAED problem is:-

$$F_t = \sum_{i=1}^N \sum_{j=1}^{M_i} F_{ij}(P_{ij}) = \sum_{i=1}^N \sum_{j=1}^{M_i} a_{ij} + b_{ij} P_{ij} + c_{ij} P_{ij}^2 \quad (20)$$

Where $F_{ij}(P_{ij})$ is the cost function of j th generator in area i and is usually expressed as a quadratic polynomial; a_{ij} , b_{ij} and c_{ij} are the fuel cost coefficients of j th generator in area i ; N is the number of areas, M_i is the number of committed generators in area i ; P_{ij} is the real power output of j th generator in area i . The MAED problem minimizes F_t subject to the following constraints

5.2.1 Active Power Balance Constraint:

$$\sum_{j=1}^{M_i-1} P_{ij} = P_{Di} + P_{Li} + \sum_{k,k \neq i} T_{ik} \quad i \in N \quad (21)$$

The transmission loss P_{Li} of area i may be expressed by using B-coefficients as

$$\sum_i^N P_{Li} = \sum_i^N \left(\sum_{l=1}^{M_i} \sum_{j=1}^{M_i} P_{ij} B_{ilj} P_{il} + \sum_{j=1}^{M_i} B_{0ij} P_{ij} + B_{00i} \right) \quad (22)$$

where P_{Di} real power demand of area i ; T_{ik} is the tie line real power transfer from area i to area k . T_{ik} is positive when power flows from area i to area k and T_{ik} is negative when power flows from area k to area i .

5.2.2 Tie Line Capacity Constraints:

The tie line real power transfer T_{ik} from area i to area k should not exceed the tie line transfer capacity for security consideration.

$$-T_{ik}^{\max} \leq T_{ik} \leq T_{ik}^{\max} \quad (23)$$

Where $T_{ik}^{\max}$ the power flow is limit from area i to area k and $-T_{ik}^{\max}$ is the power flow limit from area k to area i.

5.2.3 Real Power Generation Capacity Constraints:

The real power generated by each generator should be within its lower limit $P_{ij}^{\min}$ and upper limit $P_{ij}^{\max}$, so that

$$P_{ij}^{\min} \leq P_{ij} \leq P_{ij}^{\max} \quad i \in N \quad j \in M_j \quad (24)$$

5.2.4 Prohibited Operating Zone:

The feasible operating zones of unit can be described as follows:-

$$\begin{aligned} P_{ij}^{\min} &\leq P_{ij} \leq P_{ij,1}^l \\ P_{ij,m-1}^u &\leq P_{ij} \leq P_{ij,m}^l; \quad m = 2, 3, \dots, n_{ij} \\ P_{ij,n_{ij}}^u &\leq P_{ij} \leq P_{ij}^{\max} \end{aligned} \quad (25)$$

Where m represents the number of prohibited operating zones of j the generator in area i. $P_{ij,m-1}^u$ is the upper limit of (m - 1)th prohibited operating zone of jth generator in area i. $P_{ij,m}^l$ is the lower of mth prohibited operating zone of j the generator in area i. Total number of prohibited operating zone of jth generator in area i is n_{ij} .

6. Test System:

6.1 Single Area Six Unit System:

This system consists of six generating units, The total power demand is 1263 MW. Prohibited operating zones of each generator have been considered here with transmission loss. The entire generator data and B coefficients are taken from[16].The problem is solved by PSO,BA and FPA .The results obtained by the three algorithms is compared with each other and the convergence characteristics of algorithms is shown in fig-1.

Table 1: Simulation Result For single area six unit system

	FPA	BA	PSO
P_1 (MW)	438.5482	447.5761	474.9573
P_2 (MW)	167.3454	173.4012	178.7870
P_3 (MW)	274.7946	263.5536	262.3596
P_4 (MW)	136.0322	139.0129	133.8642
P_5 (MW)	159.8192	165.5552	152.0546
P_6 (MW)	99.1532	87.2071	74.3319
P_L (MW)	12.3000	12.8328	12.4526
Cost (\$/h)	15,442	15,447	15,452
CPU time (s)	4.256	5.112	6.489

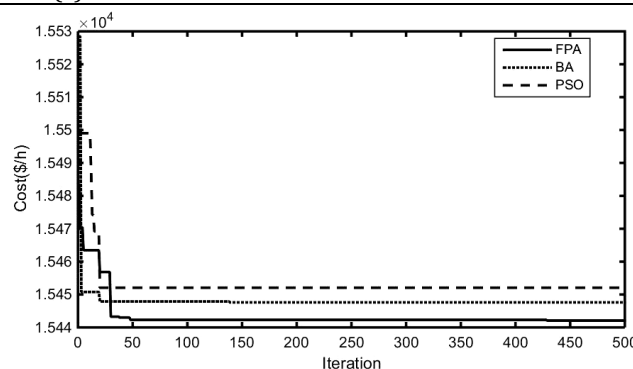


Figure 1: Iteration Vs Cost Curve for Single area six unit system

6.1.2 Two Area Six Unit System:

In this system six generator single area system is decomposed into two area with three generators on each with consideration of prohibited operation zones and transmission loss. The total demand for two area system is 1263MW and it is shared by two areas, area1 demand is 757.8MW (60%), area2 demand is 505.2MW (40%). and Tie-line power flow limit of the system is 100 MW. The problem is solved by PSO,BA and FPA. The results obtained by the three algorithms is compared with each other and the convergence characteristics of algorithms is shown in fig-2.

Table 2: Simulation Result For Two area six unit system

	FPA	BA	PSO
P _{1,1} (MW)	500.0000	500.0000	500.0000
P _{1,2} (MW)	200.0000	200.0000	200.0000
P _{1,3} (MW)	149.6134	149.6093	149.4261
P _{2,1} (MW)	204.1206	206.4481	205.7301
P _{2,2} (MW)	154.6103	154.6758	155.7290
P _{2,3} (MW)	67.5768	65.1840	65.2231
T ₁₂ (MW)	82.3866	82.3826	82.2067
P _{L1} (MW)	9.2135	9.2134	9.2097
P _{L2} (MW)	4.0945	4.0877	4.2064
Cost (\$/h)	12252.35	12254.38	12255.41
CPU time (s)	7.8641	9.9612	11.0089

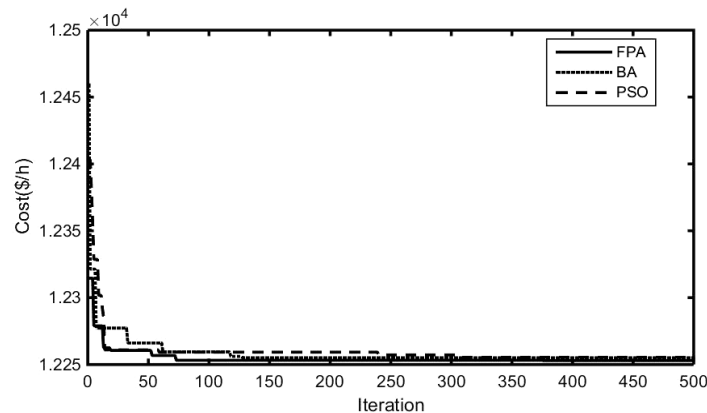


Figure 2: Iteration Vs Cost Curve for Two area six unit system

6.2 Single Area with Ten Unit System:

This system consists of ten generating units; the total power demand is 2700 MW. Multi-fuel option of each generator have been considered here without transmission loss. The entire generator data are taken from[16].The problem is solved by PSO,BA and FPA .The results obtained by the three algorithms is compared with each other and the convergence characteristics of algorithms is shown in fig-3.

Table 3: Simulation Result For single area ten unit system

	FPA		BA		PSO	
		Fuel		Fuel		Fuel
P ₁ (MW)	225.0893	2	225.0943	2	225.5446	2
P ₂ (MW)	211.2476	1	211.2537	1	210.2665	1
P ₃ (MW)	490.8353	2	490.0159	2	491.3842	2
P ₄ (MW)	240.7118	3	240.7175	3	240.9954	3
P ₅ (MW)	254.2451	1	254.1340	1	251.1047	1
P ₆ (MW)	235.5809	3	235.5870	3	238.9601	3
P ₇ (MW)	263.0884	1	263.9780	1	264.1904	1
P ₈ (MW)	237.1411	3	237.0949	3	236.0998	3
P ₉ (MW)	328.8254	1	328.8316	1	326.6392	1
P ₁₀ (MW)	248.9499	1	248.9550	1	250.4337	1

Cost (\$/h)	624.39	624.5139	625.8136
Time (s)	6.5319	7.4963	12.0381

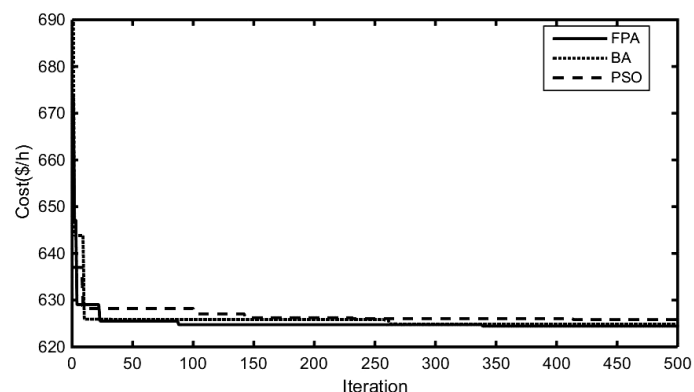


Figure 3: Iteration Vs Cost Curve for single area ten unit system.

6.2.1 Three Area with Ten Unit System:

Table 4: Simulation Result for Three area ten unit system

	FPA		BA		PSO	
		Fuel		Fuel		Fuel
P _{1,1} (MW)	225.0632	2	225.9431	2	225.4448	2
P _{1,2} (MW)	211.2215	1	211.1594	1	210.1667	1
P _{1,3} (MW)	490.8092	2	489.9216	2	491.2844	2
P _{1,4} (MW)	240.0623	3	240.6232	3	240.8956	3
P _{2,1} (MW)	254.2190	1	254.0397	1	251.0049	1
P _{2,2} (MW)	235.5548	3	235.4927	3	238.8603	3
P _{2,3} (MW)	263.9462	1	263.8837	1	264.0906	1
P _{3,1} (MW)	237.1150	3	237.0006	3	236.9982	3
P _{3,2} (MW)	328.7993	1	328.7373	1	326.5394	1
P _{3,3} (MW)	248.9238	1	248.8607	1	250.3339	1
T ₂₁ (MW)	99.3310		99.8288		99.468	
T ₃₁ (MW)	100.0647		99.7334		100	
T ₃₂ (MW)	31.6448		31.2615		30.281	
P _{L1} (MW)	17.5418		17.2095		17.268	
P _{L2} (MW)	9.2846		9.8488		9.7688	
P _{L3} (MW)	8.8884		8.6037		8.5905	
Cost (\$/h)	653.5641		653.8115		654.4134	
Time (s)	60.9746		72.4683		80.0961	

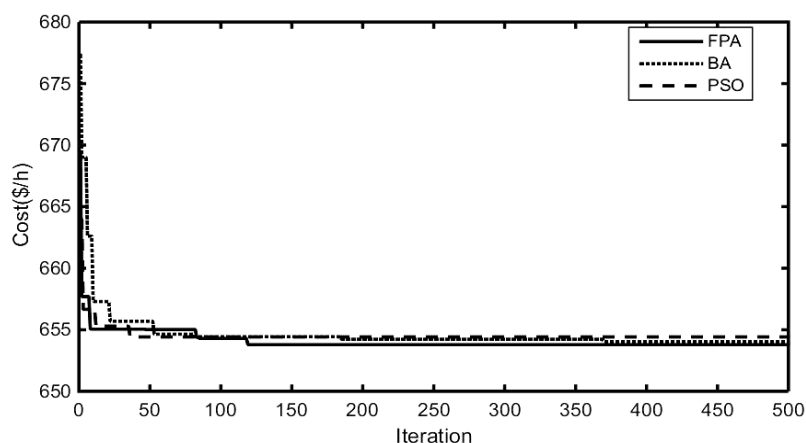


Figure 4: Iteration Vs Cost Curve for Three area ten unit system.

This test system has ten generating units with valve point loading, multi fuel options and transmission losses are also considered. The total demand for three areas is 2700MW and it is shared by three areas, area1 demand is 1350MW (50%), area2 demand is 675MW (25%), area3 demand is 675MW (25%) and the tie-line power flow limit between area 1 and area 2 or from area 2 and area 1 is 100MW.the tie-line power flow limit between area 1 and area 3 or from area 3 and area 1 is 100MW.the tie-line power flow limit between area 3 and area 2 or from area 2 and area 3 is 100MW.so all the three tie line in area three having the same limit as 100MW,the loss coefficients for the two area generators are given in[16].The problem is solved by PSO,BA and FPA .The results obtained by the three algorithms is compared with each other and the convergence characteristics of algorithms is shown in fig-4.

6.3 Single Area with Forty Unit System:

This system consists of forty generating units, The total power demand is 10500 MW. valve point effect of each generator have been considered here without transmission loss. The entire generator data are taken from[16].The problem is solved by PSO,BA and FPA .The results obtained by the three algorithms is compared with each other and the convergence characteristics of algorithms is shown in fig-5.

Table 5: Simulation Result for single area Forty Unit System

Power(MW)	FPA	BA	PSO
P ₁	110.8209	110.8212	110.2513
P ₂	110.8204	110.8216	111.0572
P ₃	97.4205	97.4216	97.6536
P ₄	179.7537	179.7549	179.9845
P ₅	87.8205	87.8212	92.9583
P ₆	140.0206	140.0213	140.2513
P ₇	259.62	259.6209	259.8517
P ₈	282.1178	284.621	284.0094
P ₉	284.6203	284.4713	284.8517
P ₁₀	130.0236	130.5247	130.2541
P ₁₁	94.0207	94.2153	169.5481
P ₁₂	94.0159	94.0051	169.0521
P ₁₃	214.7806	214.7808	215.0119
P ₁₄	393.22	394.4525	304.7717
P ₁₅	397.38	394.1574	394.5841
P ₁₆	396.49	394.1589	394.2684
P ₁₇	489.61	489.5478	489.5314
P ₁₈	489.35	489.1257	489.2796
P ₁₉	509.21	511.1571	511.533
P ₂₀	511.42	511.3497	511.531
P ₂₁	521.48	523.4238	523.4769
P ₂₂	524.86	523.5678	523.5306
P ₂₃	519.41	523.2754	523.6932
P ₂₄	517.75	523.5671	523.5345
P ₂₅	518.52	523.2961	523.5306
P ₂₆	523.3	523.2351	523.4054
P ₂₇	10	10	10
P ₂₈	10	10	10
P ₂₉	10	10	10
P ₃₀	87.0412	87.0426	88.0521
P ₃₁	190	190	190
P ₃₂	190	190	190
P ₃₃	190	190	190
P ₃₄	164.8204	164.8238	165.0235
P ₃₅	200	194.4148	165.0549

P ₃₆	194.4179	200	165.1247
P ₃₇	110.5423	110.1974	110.2513
P ₃₈	110.2589	110.4136	110.5689
P ₃₉	110.0206	110.0213	110.4796
P ₄₀	511.3	511.3007	511.5307
cost(\$/h)	122596.09	123981.69	124793.4
Time(s)	13.86	16.62	19.17

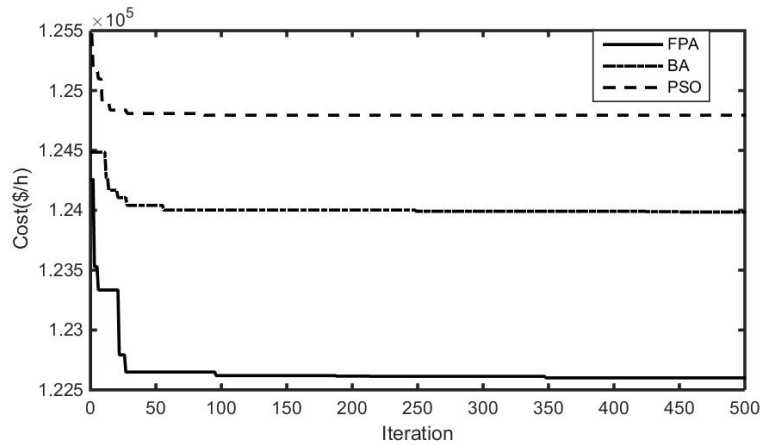


Figure 5: Iteration Vs Cost Curve for Single area forty unit system.

6.3.1 Four Area with Forty Unit System:

This test system has forty generating units with valve point loading effect without transmission loss. The total demand for three areas is 10500MW and it is shared by for areas, area1 demand is 1575MW (15%), area2 demand is 4200MW (40%), area3 demand is 3150MW (30%), area4 demand is 1575MW (15%) and the tie-line power flow limit between area 1 and area 2 or from area 2 and area 1 is 200MW. the tie-line power flow limit between area 1 and area 3 or from area 3 and area 1 is 200MW. the tie-line power flow limit between area 3 and area 2 or from area 2 and area 3 is 200MW. the tie-line power flow limit between area 4 and area 1 or from area 1 and area 4 is 100MW. the tie-line power flow limit between area 4 and area 2 or from area 2 and area 4 is 100MW. the tie-line power flow limit between area 3 and area 4 or from area 4 and area 3 is 100MW. The generator data are taken from [26]. The problem is solved by PSO, BA and FPA. The results obtained by the three algorithms is compared with each other and the convergence characteristics of algorithms is shown in fig-6.

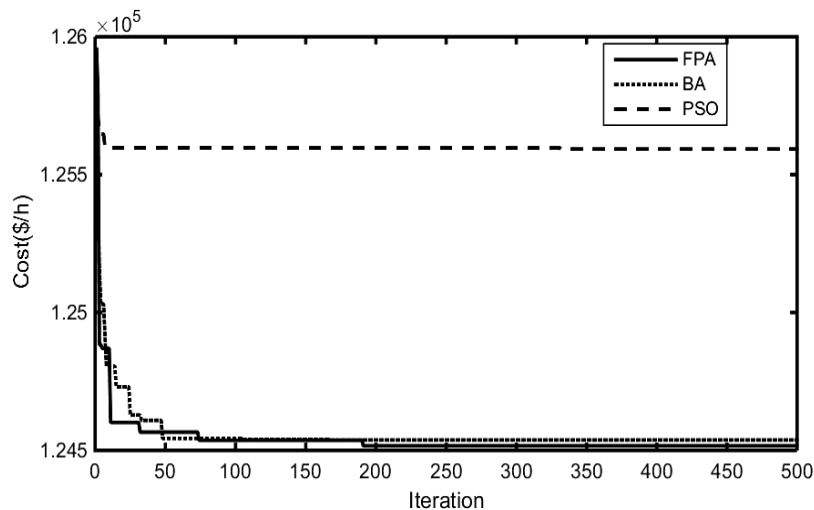


Figure 5: Iteration Vs Cost Curve for Single area forty unit system.

Table 6: Simulation Result for Four area forty unit system

Power(MW)	FPA	BA	PSO
P _{1,1}	111.1893	93.1735	114
P _{1,2}	110.0647	109.1501	114
P _{1,3}	101.0111	89.8402	63.8677
P _{1,4}	190	117.0398	138.9798
P _{1,5}	97.0263	97.4523	75.4196
P _{1,6}	97.0548	140.0909	106.5167
P _{1,7}	259.7823	283.8175	300.0951
P _{1,8}	276.0873	286.3555	300.0951
P _{1,9}	300	284.1818	284.0951
P _{1,10}	134.785	131.7258	136.8286
P _{2,1}	245.1813	169.9653	175.4569
P _{2,2}	94.0806	111.0623	94.093
P _{2,3}	125.0806	229.976	263.9056
P _{2,4}	434.0806	387.5657	331.1475
P _{2,5}	390.7549	427.8458	394.3121
P _{2,6}	395.0849	478.3695	413.1885
P _{2,7}	500	490.2734	499.7693
P _{2,8}	500	491.0391	500
P _{2,9}	530.8695	511.0915	533.9258
P _{2,10}	514.4896	511.9156	508.093
P _{3,1}	527.2759	547.7267	520.7627
P _{3,2}	502.1565	523.5881	531.0762
P _{3,3}	530.4427	522.723	550.0762
P _{3,4}	542.4194	545.0944	531.8139
P _{3,5}	520.3218	523.7552	526.8292
P _{3,6}	533.7159	527.4621	549.7158
P _{3,7}	10.452	10.0944	10.0762
P _{3,8}	10.756	15.8795	10.4238
P _{3,9}	10.077	10.0944	10.4869
P _{3,10}	96.427	93.1197	89.8351
P _{4,1}	187.0991	185.1587	173.6336
P _{4,2}	168.7832	157.1247	189.0971
P _{4,3}	173.7156	188.2543	116.5281
P _{4,4}	186.4731	198.2476	180.7525
P _{4,5}	200	90.0897	162.1887
P _{4,6}	165.0561	149.5437	173.1891
P _{4,7}	92.6618	109.0897	109.5225
P _{4,8}	96.0991	88.2527	74.4313
P _{4,9}	109.9144	25.0897	99.7885
P _{4,10}	431.5002	538.5592	541.0971
T ₁₂	190.851	199.1661	199.1139
T ₁₃	10.8172	90.7073	96.1139
T ₃₂	185.3284	149.0653	188.1286
T ₄₁	86.1432	49.2499	44.3425
T ₄₂	96.4669	40.1661	99.1139
T ₄₃	55.3624	71.0693	100
cost(\$/h)	124512.6	124536.8	125591.7
Time(s)	97.63	108.71	115.86

7. Conclusion:

The results of the study show the importance of the multi area economic dispatch and the comparison of results for the test cases shows that the FPA method is capable of obtaining higher quality solution efficiently for higher degree ELD problems. The convergence tends to be improving as the system complexity increases. Thus

solution for higher order systems can be obtained in much less computation time duration than the BA and PSO.

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