MULTI OBJECTIVE ECONOMIC /EMISSION DISPATCH OF THERMAL POWER PLANT USING HYBRID ALGORITHM

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CERTIFICATE

Certified that the thesis entitled, "**MULTI OBJECTIVE ECONOMIC EMISSION / EMISSION DISPATCH OF THERMAL POWER PLANT USING HYBRID ALGORITHM**" is an authentic record of research carried out by Sri Ritunjoy Bhuyan for degree of Doctor of Philosophy of Gauhati University under my supervision and guidance.

I further certify that the candidate has fulfilled all criteria under existing norms for submission of current Ph. D. thesis which is found to be original in kind and based on his own findings and close observation.

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DECLARATION

I hereby declare that the thesis entitled, **"MULTI OBJECTIVE ECONOMIC/EMISSION DISPATCH OF THERMAL POWER PLANT USING HYBRID ALGORITHM"** is an authentic record of my original research work carried out under the guidance of Dr. Sarmila Patra, Associate Professor, Department of Electrical Engineering, Assam Engineering College, Gauhati University, Guwahati-781014, Assam, India.

I further declare that this thesis as a whole or any part thereof has not been submitted to any university (or institute) for the award of any degree or diploma.

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Dated:

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TO

MY LOVING PARENTS

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(Sri Ritunjoy Bhuyan)

ABSTRACT

Economic Dispatch (ED) optimization problem requires load allocation to each generator of a group of generators parallel connected to minimize operating cost simultaneously fulfilling the load demand without violating the generation limit. The main source of power generation being fossil fuel in power plants the emission of harmful gases like SO_x, CO_xNO_x are detrimental to the environment and degrade the quality of air. As a consequence of this, the fuel cost and emission minimization in power plants have become a new paradigm of research in recent years. The conglomeration of the objective of emission minimization with fuel cost minimization is termed as Combined Economic Emission Load Dispatch (CEED).The problem of CEED is a complex problem and needs to be addressed from multi objective approach because of involvement of two conflicting objective function.

Initially conventional methods were applied to solve this problem. But due of complex nature of this problem evolutionary algorithms like GA, PSO, DE, ACO were later on used by researchers. In this thesis GA, TLBO hybrid GA-TLBO and sequential quadratic programming based TLBO will be explored for solution of this problem.

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CHAPTER 1

1. Introduction

The fundamental goal of a power system to deliver high quality of power to the consumers in a secure and economic way. The ever escalating energy demand accompanied by the rising fuel price and ever increasing population, has led researchers to delve into economic operation of power system. Also the main source of power generation being fossil fuel in power plants the emission of harmful gases like SOx, Cox, NOx are detrimental to the environment and degrade the quality of air. As a consequence of this, the fuel cost and emission minimization in power plants have become a new paradigm of research in recent years. Proper co-ordination and control of generation level of all the generators will be a great initiative towards fuel cost reduction. Using fuels with low emission, installation of cleaning system, dispatch of generation with the objective of emission minimization will play a significant role for emission reduction.

Economic load dispatch (ELD) involves the determination of power level of the generating units with minimum cost of generation thereby satisfying all the operational constraints. The conglomeration of the objective of emission minimization with fuel cost minimization is termed as Combined Economic Emission Load Dispatch (CEED).The problem of CEED is a complex problem and needs to be addressed from multi objective approach because of involvement of two conflicting objective function.

Literatures [1]-[50] report the existing literatures in the paradigm of ELD and CEED.

1.1 Literature Review

Gent et al. [1] are the pioneers in this paradigm of research who initiated the works on minimum emission of oxides of nitrogen along with cost. Later Schweppe et al. [2] reported a. Brodsky et al. [3] in 1986 presented a new approach of pooling arrangements between production costs and emissions. M. R. Alrashidi et al, 2008 [4] presented the influence of loading on the emission and economic dispatch problem. They utilized weighting functions on the double and conflicting objective of emission and fuel cost accompanied by a simplified way of addressing the equality constraint. Nanda. J [5] proposed a new approach of defining emission load dispatch problem that accounts for minimization of both emission and cost which is multiple, conflicting objective of function problem.

Though the main objective of CEED is optimal dispatch of power with the objective of cost and emission minimization, the complex and dynamic nature of this problem has led researchers to apply different techniques for solution of this problem. The literatures of this area is broadly classified as-

Literatures utilizing conventional methods for solution

Literatures utilizing evolutionary algorithms for solution

Literatures utilizing hybrid algorithms for solution

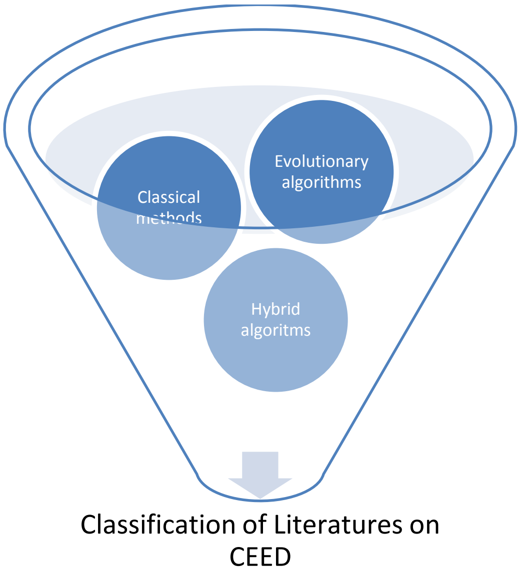


Fig.1.1- Classification of literatures on CEED

1.1.1 Literatures utilizing conventional methods for solution

Conventionally classical optimization technique such as Langarangian Relaxation [6], Integer programming [11], Lambda iteration [14], Newton Raphson Method [9] were used for solution of CEED problem. All the aforementioned methods are based on derivative information of the objective function.

Guan X et alin 1992[6] proposed an optimization method applying Lagrangian Relaxation Technique.

Ahmed Farag, in 1995 [7] utilizes linear programming for solution of this multi-objective problem. The constriction factor approach is utilized by them for dealing with the inequalities.

Chang et al., in 1995 [8] uses bi criterion global optimization for solution of this multi- objective problem.

Chen et al., in 1997 [9] utilized the fast Newton Raphson method based on an alternative Jacobian matrix formulated based on sensitivity factor to solve CEED with line flow limits.

Das et al., in 1998 [10] proposed a solution methodology of security constrained CEED by stochastic search technique. The main objective of their work was minimization of cost and emission simultaneously thereby maintaining security constraint.

Srivastava V.K. et al in 2001[11] proposed a two phase optimization method of integer programming problem with a linear or non linear objective function

Celal Yasar et al in, 2005 [12]. Gives first order gradient method for solving the CEED problem. They reported that the proposed methodology of solving this complex problem has the benefit of unproblematic and flexible constraints control. However not possessing a well defined option for the selection of α_G whichis one of the essential parameters for the speed of convergence is the inherent shortcoming of the aforementioned methodology.

J Nanda et al. [13] proposed a novel methodology inspired by classical technique taking into account the line flows expressed in terms of active power.

Naresh M et al2014 [14] explained classical Lambda Iteration technique together with some other techniques to solve CEED

Because of the complex and dynamic nature of this problem the use of evolutionary algorithms for solution of this problem has attracted the interest of researchers. Evolutionary algorithms or nature inspired algorithms like Genetic algorithms (GA) [16], Differential evolution (DE) [20], Simulated Annealing (SA) [50], Ant Colony Optimization (ACO) [40], and Particle Swarm Optimization (PSO) [21] are used profoundly for solution of this optimization problem.

Song et al., in 1995 [15] used GA for solution of this multi-objective problem. Their main objective was cost minimization thereby satisfying emission constraint.

In 2002Atun et al. [16] proposed a modified GA with operation of arithmetic crossover and mutation for solution of CEED.

In 2003Abibo et al [17] used niched pareto genetic algorithm (NPGA) for solution of CEED problem. The algorithm proposed by them has better convergence criterion than GA and does not suffer from the drawback of premature convergence.

Sudhakaran et al in 2004 [18]further developed a refined version of GA and applied that for solution of CEED.

Rahmanet al., in 2004[19] presented Artificial Immune System using clonal selection principle to solve economic dispatch problem. The algorithm was tested on binary as well as real number representation.

In 2005, Perez et al. [20] used DE for solution of CEED. They carried out their work first by considering emission as constraint and then emission as objective function. A comparative analysis of the results obtained by both the aforementioned approach is also provided in their work.

Wang et al., in 2006 [21] formulated multi area CEED and used multi-objective PSO for its solution. System security limits as well as spinning reserve limits were incorporated in this new approach of problem formulation.

Al Rashidi et al., 2006 [22] also utilized PSO for solution of PSO. They considered minimization of fuel cost, Coxemission, Soxemission and NOxemission as the objective function.

Liu et al., 2006 [23] used Immune GA (IGA) for solution of CEED. They validated this algorithm on five units fossil fuelled power plant.

Hazra et al., 2008 [24] used Bacteria Foraging Algorithm (BFA) for solution of CEED. The results obtained showed that this algorithm can work efficiently on large practical systems.

Chaturvediet al., 2009 [25] used PSO with time varying acceleration coefficient for CEED problem to control the local and global search and to avoid the drawback of premature convergence in classical PSO.

Kothari et al., 2009 [26] proposed a binary successive approximation based evolutionary search strategy for solving CEED. The multi objective problem was converted to single objective function by assigning proper weights to all the objective functions.

Wu et al., 2009 [27] used multi- objective DE with crowding entropy based diversity to solve CEED.

Basu et al., 2010 [28] used multi-objective DE to solve CEED. The method used was simple and efficient for solving this complex problem. Moreover there was no limitation regarding the number of objective functions that can be considered while applying this method.

Gaurav Prasad et al, 2011 [29] applies a new and novel method called Artificial Bee Colony (ABC) to solve the economic load dispatch problem. In comparison to other heuristic methods it possesses characteristics like stable convergence characteristics and good computational efficiency which makes it superior to other algorithms.

Y. Sonmez et al, 2011 [30] applied the Artificial Bee Colony method to solve the multi-objective economic environmental dispatch problem using the penalty factor approach.

Basu et al., 2011 [31] utilized the MODE algorithm for solving CEED problem. The results obtained from the proposed algorithm proved its superiority over NSGA II algorithm.

Dhanalakshmi et al., 2011 [32] added the concept of crowding distance to NSGA II and utilized this to obtain solution of NSGA II.

Niknam et al., 2011 [33] used self adaptive PSO for solution of CEED with non smooth operation. The inertia weight of PSO was tuned by fuzzy logic and it restricted premature convergence.

Niknam et al., 2011 [34] used Chaotic Modified Shuffled Frog Leaping Algorithm (CMSFLA) to solve CEED. This algorithm has the inherent capacity of avoiding local optima.

Soni et al, 2012 [35] utilized DE algorithm for multi-objective emission constrained economic power dispatch problem. The space of searching was explored by randomly choosing the initial candidate solutions and using mutation, crossover and selection operators. The developed technique is simple and possesses good convergence characteristics.

Parihar, 2012 [36] introduced a novel and unique approach based on Fuzzy ranking combined with GA to deal with multi-objective problem of fuel cost, emission and system loss minimization.

Damousiset al., 2013 [37] utilized real-coded GA to minimize the dispatch cost while satisfying generating unit and branch power-flow limits. In the proposed work, author used floating–point numbers for coding of the generator outputs instead of the typical binary representation. This method has improved the accuracy of the algorithm and also reduced the execution time.

Sahuet al., 2013[38] presented Genetic Algorithm based approach to solve CEED problem. They carried out the work on IEEE 14 and IEEE 30 bus test cases and compared the results with quadratic programming by including the transmission losses. The results obtained established the superiority of GA over the conventional method.

Hamedi et al, 2013 [39] proposed an advanced parallelized synchronous particle swarm optimization (PSPSO) algorithm for finding the optimal power generation units that minimizes the fuel cost and emission. In this algorithm, positions and velocities are updated at the end of each iteration and the time required for solving CEED reduced substantially by using parallel computation.

1.1.2. Literatures utilizing hybrids methods for solution

F Waiel et al, [40] has applied hybrid ACO-MSM in Economic Emission Load Dispatch problem in two test examples and superiority of the approach established by comparing with other techniques

Biswas et al. [41] reported a hybrid approach combining BF and DE algorithms in 2009.

Senthi K, al2010, [42] proposed a lambda based approach to solve Combined economic emission dispatch problem using evolutionary programming method considering the power limit with sample test system of three and six generators

In 2010, Bhattacharya and Chattopadhyay [43] presented application of hybrid DE-BBO method in ELD problem taking into account transmission losses, and constraints such as ramp rate limits, valve-point loading, and prohibited operating zones.

Younes and Benhamidaet, al 2011[44] proposed a hybrid GA-PSO method was proposed

Manteaw Dartey Emmanuel etal 2012 [45] has applied ABC-PSO in EECO on 10 generator system with valve point effect and the results are compared with differential evolution techneque, NSGA method etc.

A.M. Elaiwa, X. Xiab and A.M. Shehata, [46] proposed a Hybrid DE-SQP and hybrid PSO-SQP methods for solving dynamic economic emission dispatch problem with valve-point effects in 2013.

Hareesh S. et, al 2016[47] gave a method of solution of Combined economic emission dispatch problem by hybrid Firefly-DE algorithm which was proven to be effective.

Victoire et al [48] gave a novel and efficient method for solving the economic dispatch problem (EDP), on the Particle Swarm Optimization (PSO) with Direct Search (DS) method incorporated. The heuristic integrates DS method with the PSO and fine tunes every improvement of solution of the PSO run. The PSO is used with a linear inertia weight to facilitate a global and local search as the algorithm proceeds. The optimization

Dubey et al. [49] have proposed a hybrid PSO-GSA method to solve ELD problem.

Sundaramet, al [50]This paper presents hybrid approach of using Artificial Bee Colony (ABC) and Simulated Annealing (SA) algorithm to solve highly constrained non-linear multi–objective Combined Economic and Emission Dispatch (CEED) having conflicting economic and emission objective.

1.2. Motivation of the research work

This profound review of existing works in the paradigm of CEED presented here gives an overall idea about the methodologies and approaches applied to CEED. Initially conventional methods were applied to solve this problem. But due of complex nature of this problem evolutionary algorithms like GA, PSO, DE, ACO were later on used by researchers. Though the performances of the aforementioned algorithms are satisfactory, but still researchers are working on developing more sophisticated algorithms for solution of this problem.

In this thesis GA, TLBO, hybrid GA-TLBO and sequential quadratic programming based TLBO will be explored for solution of this problem. In a nutshell the objectives of this research work are as follows-

1. To study multi objective power system problem in term of fuel cost and emission
2. By using penalty factor, multi objective function is converted to single objective function
3. Study SQP, GA and TLBO Models
4. To formulate algorithm of hybrid model of GA and TLBO to solve CEED
5. To formulate algorithm of hybrid model of SQP and TLBO to solve CEED
6. To test on IEEE 30 BUS 6-generartors, 10 -generators and 13 -generators system.
7. To compare the hybrid results with the results of others method.

1.3. Organization of Thesis

The thesis contains six chapters. Chapter 1 consists of Overview of the problem, literature review, thesis objective and thesis organization.

Chapter 2 narrates economic emission dispatch in detail.

In chapter 3 Genetic optimization technique is explained in detail and application of GA to combined economic emission dispatch together with the results and discussions are shown in tabular format as well as graphically.

Chapter 4 contains description of Teaching Learning Based Optimization technic. Application of TLBO to CEED and the results and discussions are shown in tabular format as well as graphically in this chapter 4.

In chapter 5, solution of CEED by hybrid GA-TLBO is discussed with example and comparative results of GA & GA-TLBO application to CEED and discussions thereof are shown in tabular format as well as graphically.

In chapter 6 an overview of TLBO &Sequential Quadratic Programming optimization technique is discussed. The solution of CEED by hybrid TLBO-SQP is shown with example. Comparative results of TLBO, GA-TLBO & TLBO-SQP application to CEED and discussions thereof are shown in tabular format as well as graphically.

Chapter 7 is the conclusion of the thesis giving summery of the application of different modern optimization technics to Combined Economic Emission Dispatch Problem.

CHAPTER 2

Problem Formulation of combined economic emission dispatch

2.1 Combined Economic Emission Dispatch

To improve the overall efficiency of the electrical Power System, system operation must be carried out in optimal condition which necessitates economical operation, secured system, fossil fuel plant with moderate emission of toxic gas with flue gas of the chimney, hydroelectric power plant with optimum releasing of water at tail race

From the consumers' point of view, economical dispatch of power is one of the important aspect to be considered by the agencies related to the generation, transmission and distribution of Electrical power. The process leads to the optimization problem of dispatching power which demands a meticulous planning for the power output from each engaged generator with minimized operating cost and meeting up of the constraints like power demand , stability etc satisfactorily. Conventionally, electrical power system are operated based on minimizing operational cost while maintaining system constraints..While the consideration of generator cost is done, fuel cost, labor cost, maintenance cost and supply cost come into the picture.

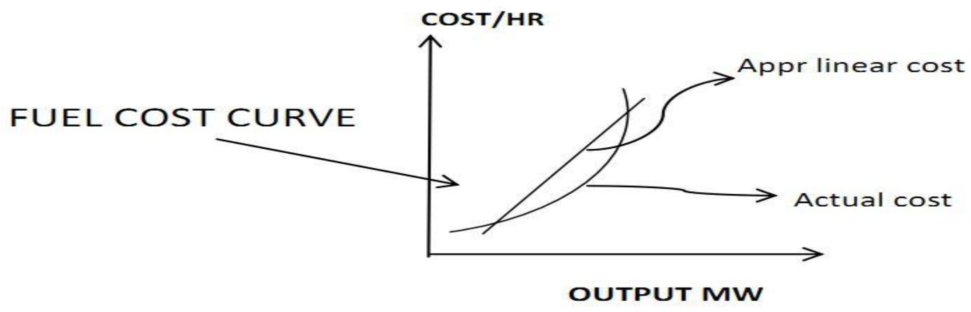


Fig 2.1-fuel cost curve

From the curve it is very much clear that the fuel cost is a quadratic function of out put power. But practically , the cost function is not a smooth one , the system is not static in character as well , there is lot of toxic emission which are not taken into consideration and there is start up and shut down cost . Obviously the above curves are based on some assumption of absence of the above factors which are practically significant in power system.

2.1.1 Emission Dispatch Consideration

The operation at minimum fuel cost level causes environmental pollution problems against the enforcement of environmental regulations. Specially emission from the combusted fossil fuels by the prime-mover-operation of the generators stand as a great threat to the pollution free environment demanded by the increasing public awareness of the environmental pollution.. So, the ED Optimization technic should also consider the environmental pollution scenario.

These emissions can be reduced by

1) using low emission potential fuels
2) installing post combustion cleaning equipment
3) allocation of load to individual generator keeping in view minimum emission dispatch

Because of the easy implementation process and requirement of minimum additional costs, the third method is becoming popular gradually. A price penalty factor is used to fit the emission control criteria into the objective function. Thus ECONOMIC EMISSION DISPATCH OF LOAD “is the most recent optimization problem of power system which can be solved by classical as well as modern optimization techniques. But the classical technic lost its efficiency in dealing with the non linear multi objective problem with its non convex nature .As a result, Meta-heuristic methods like Genetic algorithm optimization technic, Simulated Annealing ,Particle Swam Optimization, TLBO Technic, GA-PSO Hybrid, TLBO-SQP Hybrid are brought into operation.

With the advent of these methods, the multi faceted economic dispatch problem is being addressed but the challenges being faced by the above are high computational time, converge to a local optima ,not feasible solution and malfunctioning of algorithm for large and medium size system.

2.1.2. Problem description

When environmental criteria are considered, the economic dispatch may not be optimum. Harmful ecological effects by the emission of gaseous pollutant from fossil fuel power plant can be reduced by proper load allocation among the various generating units of the plant. But this load allocation can result increased operating cost. A balanced result between emission and cost is to be found out. This can be achieved by combined economic emission problem. This dual objective problem is converted to a single objective function using a price penalty factor approach,

2.1.3. Formulation of Objective Function

Optimization of generation cost has been formulated based on classical ELD with emission and line flow constraints. The detailed problem is given [46] as follows.

$$F = \text{Min}\sum_{i=1}^{d} f_i(FC, EC) \qquad (2.1)$$

Where F is the optimal cost of generation.

FC and EC are total fuel cost and emission costs of generators, respectively.

d represents the number of generators connected in the network.

The minimum value of the above objective function has to the found out subject to constraints given by the equations (2.3) and (2.5)

$$\sum P_i = P_D + P_L \qquad (2.2)$$

Where P_D = Total load of the system

P_L =Transmission loss of the system

$$P_i^{min} \leq P \leq P_i^{max} \qquad (2.3)$$

Where P_i^{min} =minimum real power at ith generator

P_i^{max} = maximum real power at ith generator

Total fuel cost of generation FC in terms of control variables generator powers can be expressed as follows

$$FC(P) = \sum_{i=1}^{d}(a_i P_i^2 + b_i P_i + c_i) \$/h \qquad (2.4)$$

Where P_i is the real power output of an i^{th} generator in MW,

i represents the corresponding generator,

a_i, b_i , c_i are the fuel cost coefficients of generators.

The total emission release can be expressed [46] as

$$EC(P) = \sum_{i=1}^{d}(\alpha_i P_i^2 + \beta_i P_i + \gamma_i) kg/h \qquad (2.5)$$

Where α_i ,β_i ,γ_i are emission coefficients of generators.

The dual-objective combined economic emission dispatch problem is converted into single optimization problem by introducing a price penalty factor h as follows,

$$\text{Minimize}\Phi_i = FC + h \times EC \quad \$/h \qquad (2.6)$$

Subjected to the power flow constraints of equation (2.3, 2.5. The price penalty factor **h** blends the emission with fuel cost and Φ_i is the total operating cost in $/h.

The price penalty factorh_i is the ratio between the maximum fuel cost and maximum emission of corresponding generator,

$$h_i = \frac{FC(P_i^{max})}{EC(P_i^{max})} \text{ \$/kg} \quad I = 1,2,\ldots\ldots,d \tag{2.7}$$

The following steps are used to find the price penalty factor for a particular load demand;

1. Find the ratio between maximum fuel cost and maximum emission of each generator
2. Arrange the values of price penalty factor in ascending order.
3. Add the maximum capacity of each unit (P_i^{max}) one at a time, starting from the smallest h_i until $\sum(P_i^{max}) \geq P_D$.
4. At this stage, h_i associated with the last unit in the process is the price penalty factor h for the given load.

The above procedure gives the approximate value of price penalty factor computation for the corresponding load demand. Hence a modified price penalty factor (h_m) is used to give the exact value for the particular load demand the first two steps of h computation remain the same for the calculation of modified price penalty factor. Then it is calculated by interpolating the values of h, corresponding to their load demand values.

CHAPTER 3

Solution of Problem of Combined Economic /Emission Dispatch by Genetic Algorithm

3.1 Introduction:

The economic load dispatch problem deals with the determination of optimal combination of power output for all generators to minimize the total fuel cost maintaining all demands and operational constraints. But the operation at minimum fuel cost level causes environmental pollution problems. Fossil fuels like coal, gas or combinations, after being burnt, emits CO,CO_2NO_x,SO_2 ,Particulates and thermal emission.one of the methods for reduction of emission is allocation of load to individual generator keeping in view minimum emission dispatch

Thus Combined economic emission dispatch is one of the most recent optimization problem of power system which can be solved by both conventional and evolutionary optimization techniques. Here an evolutionary optimization technique–Genetic algorithm optimization is applied to solve the combined economic emission dispatch problem.

3.2 Genetic Algorithm:

It's a global optimization technique with probabilistic and heuristic approach to solve power system problem. It can cope up with non-linearity and discontinuities which are very common in optimization problems.

The basic concept of GA is ability to simulate processes in natural system following the great principle of Charles Darwin "SERVIVAL OF THE FITTEST". To solve a problem, the technique adopts a random search within a definite search space.

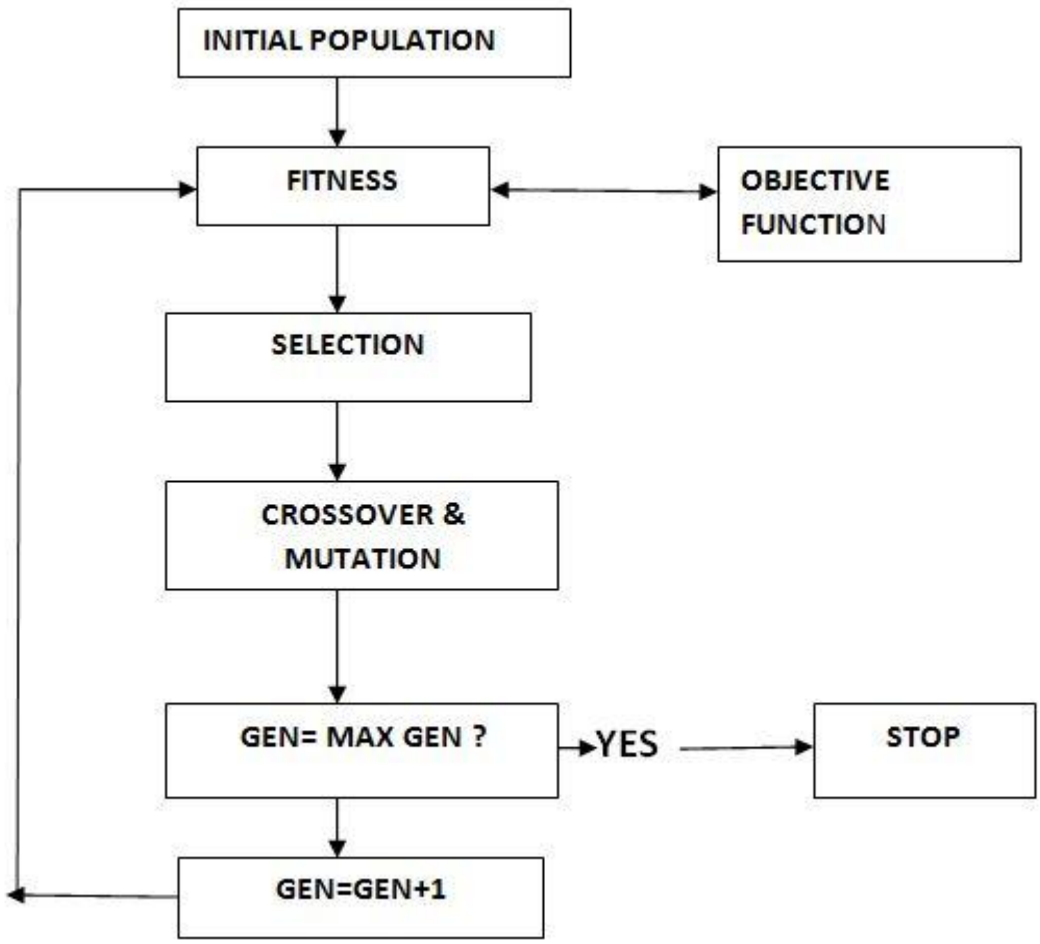
This GA optimization technique becomes a strong alternative to the classical method, overshadowing them gradually. GA can solve problems which either do not have specific method of solution or takes long time to get a solution. In contrast, GA handles the objective function information in a search space for an optimum result.

COMPONENT of GENETIC ALGORITHIM: Population genetics is the basic model of GA. It has five components:

1. String representation of control variable
2. An initial population string
3. An evaluation function that plays the role of the environment rating the fitness of the string
4. by cross over mutation or reproduction a new population is generated
5. Value of the parameters that the technique is using

There is a strong analogy between GENETIC ALGORITHIM and NATURAL GENETICS. The strings are similar to chromosomes of biology. The chromosome contains genes called "alleles" For real number control variables , it is called Real coded GA and for binary, it is called binary coded GA. GA always works with a population of strings where new string takes the place of parent. In GA, the input is string and the out put is the fitness of the string.

3.3 FLOW CHART OF GA :



In real coded GA, an individual is coded as vector of real numbers corresponding to design vector. The real coded vectors are robust, accurate and efficient because floating point representation is closer to real design space.

3.4 Operators:

The following operators are used in GA

1. Tournament selection: The selection operator improves the average quality of the population by giving individual of higher fitness a higher probability to be copied into next generation. Two individuals are selected randomly and copied the best individual into intermediate population

2. <u>Whole linear cross over</u>: This operator combines the genetic data of the existing population and generating off spring. Pair of chromosomes are recombined randomly to form two new individuals. From two parents p1 and p2 three offsprings are generated for example: 0.5p1+0.5p2, 1.5p1-0.5p2 and 0.5p1+1.5p2. Then the two bests are selected

3. <u>Non uniform mutation</u>: New genetic patterns are formed by this operator

4. <u>Elitist strategy</u>: GA do not preserve the best possible solution very often. This strategy overcomes this by copying the best to the next generation.

3.5 Application of GA to solve CEED Problem

The combined Economic Emission Dispatch is a bi-objective Problems which is converted to a single one by a cost penalty factor or hybridization factor as

$f(P_{Gi})= \text{Min}\sum_{i=1}^{nG}[\, F_i(P_{Gi}), E_i(P_{Gi})]$ (1)

where f (P_{Gi}) is the optimal cost of power generation, $F_i(P_{Gi})$ and$E_i(P_{Gi})$ are total cost and total emission, nG is the number of generators . The constraints are

$\sum_{i=1}^{nG} P_{Gi}=P_D-P_L$ where

P_{Gi},is the real power generation of ith generator, P_D and P_L are total load and transmission loss of the system

$P_{Gi}^{min}\leq P_{Gi}\leq P_{Gi}^{max}$ where

P_{Gi}^{min} and P_{Gi}^{max} are minimum and maximum real power allowed at generator I respectively

To handle the constraints, the violated constraints are squared then multiplied by a penalty coefficient and add to the fitness function.

The procedure of implementation of GA to solve CEED is described in the following steps.

Step 1: Input the total number of decision variable, population size, cross over rate, mutation rate, cost coefficients, loss coefficients, load demand and limits of the constraints. Here the decision variables are the output of generators and are considered as population

Step 2: Generate the initial population which satisfies the limits and constraints.

Step 3: Objective function (fitness) of each individual is calculated.

Step 4: Perform cross over and mutation.

Step 5: Make the selection based on fitness.

Step 6: Stop the process if maximum number of iteration is reached, otherwise repeat from step 3.

3.6 Results and Discussion

The Genetic algorithm is applied to solve ELD, EED and CEED for three different test cases: 6 unit system, the parameters of GA are:

Population size=20;

Cross over rate=80%

Mutation rate=1%

The results of solution ELD, EED and CEED by GA for 6 unit system are shown in Table 3.1, 3.2 and 3.3 respectively

Fig 3.1-3.3 shows the convergence characteristics of ELD, EED and CEED for 6 unit system by GA

Table 3. 1-Economic load dispatch for 6 generators system

Generator	Economic load dispatch
PG1	0.1183
PG2	0.3068
PG3	0.4650
PG4	1.1025
PG5	0.5463
PG6	0.3012
FUEL COST	602.47
EMISSION	0.2291
Loss	0.0533

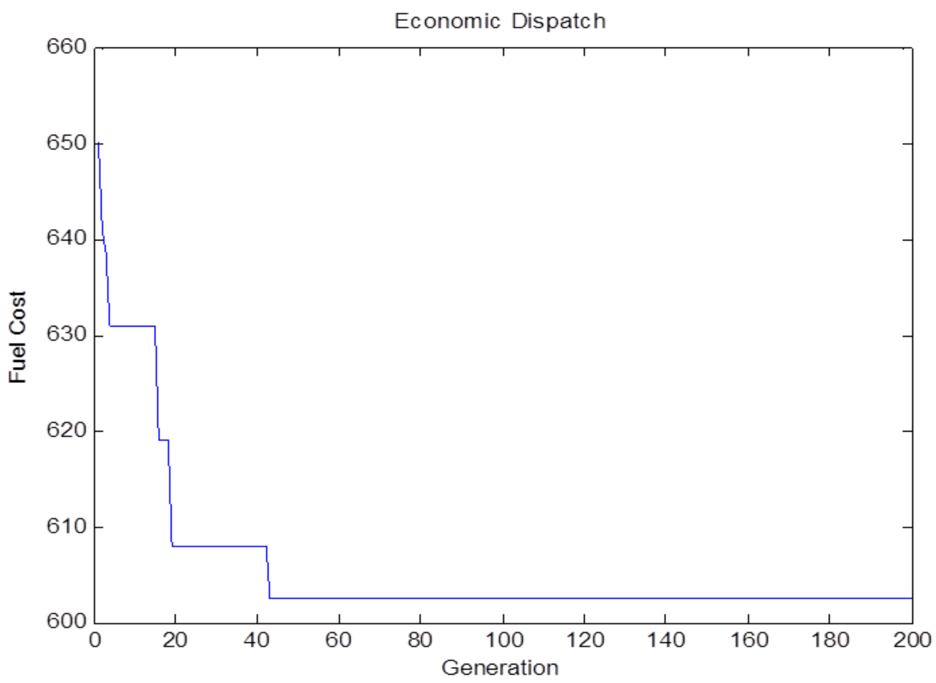


Fig 3.1-Convergence characteristic of ELD for 6 units

Table 3.2-Economic Emission dispatch for 6 generators system

Generator	Emission dispatch by GA
PG1	0.418
PG2	0.465
PG3	0.543
PG4	0.407
PG5	0.531
PG6	0.52
FUEL COST	649.04
EMISSION	0.1942
Loss	0.038

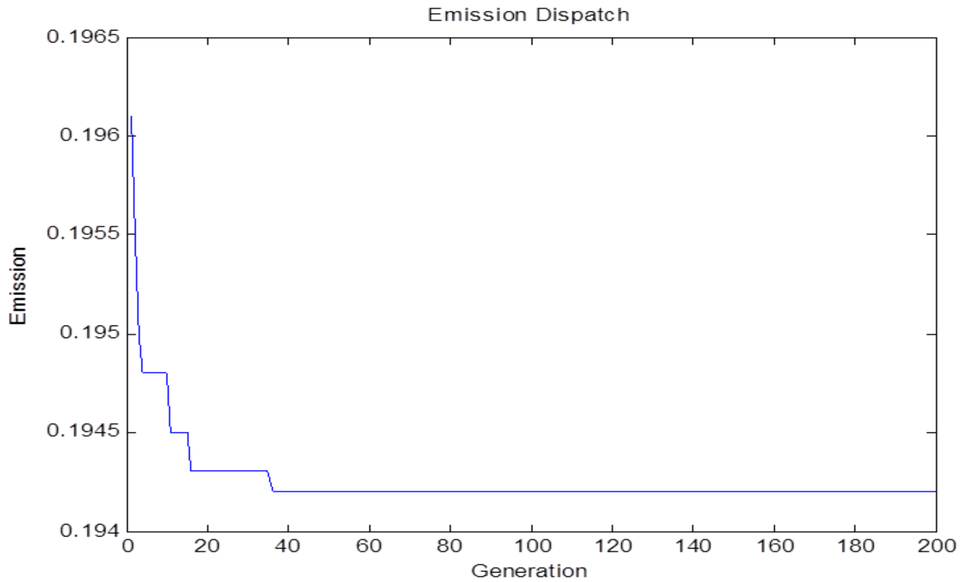


Fig3.2- Convergence characteristic of EED for 6 units

Table 3.3–Combined Economic Emission dispatch for 6 generators system

Generator	CEED by GA
PG1	0.193
PG2	0.34
PG3	0.48
PG4	0.71
PG5	0.693
PG6	0.449
FUEL COST	616.01
EMISSION	0.2044
Loss	0.044

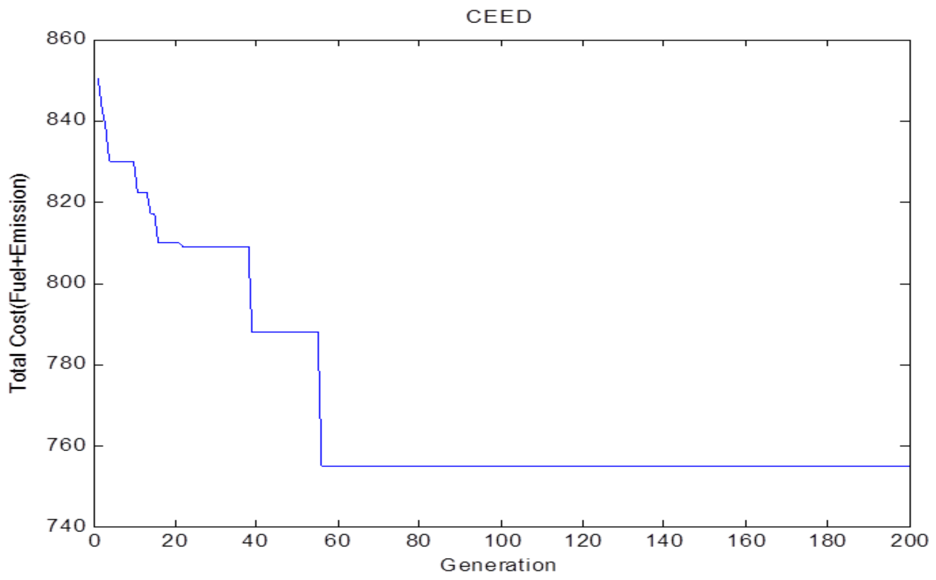


Fig 3.3-Convergence characteristic of CEED for 6 units

The results of solution ELD, EED and CEED by GA for 10 unit system are shown in Table 3.4, 3.5 and 3.6 respectively Fig 3.4-3.6 shows the convergence characteristics of ELD, EED and CEED for 10 unit system by GA

Table 3.4-Economic load dispatch for 10 generators system

Generator	**Economic load dispatch by GA**
PG1	55
PG2	80
PG3	106.93
PG4	100.57
PG5	81.49
PG6	83.01
PG7	300
PG8	340
PG9	470
PG10	470
FUEL COST	111500
EMISSION	4571.2
Loss	87.03

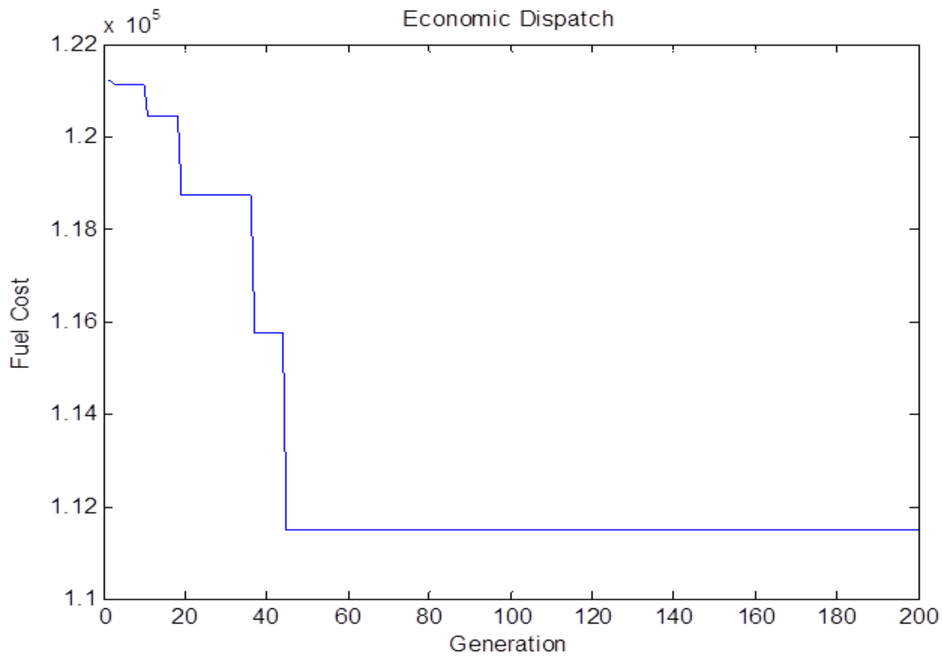


Fig 3.4-Convergence characteristic of ELD for 10 units

Table 3.5-Economic Emission dispatch for 10 generators system

Generator	**Emission dispatch by GA**
PG1	55
PG2	80
PG3	81.96
PG4	78.82
PG5	160
PG6	240
PG7	300
PG8	292.78
PG9	401.84
PG10	391.21
FUEL COST	116420
EMISSION	3932.3
Loss	87.03

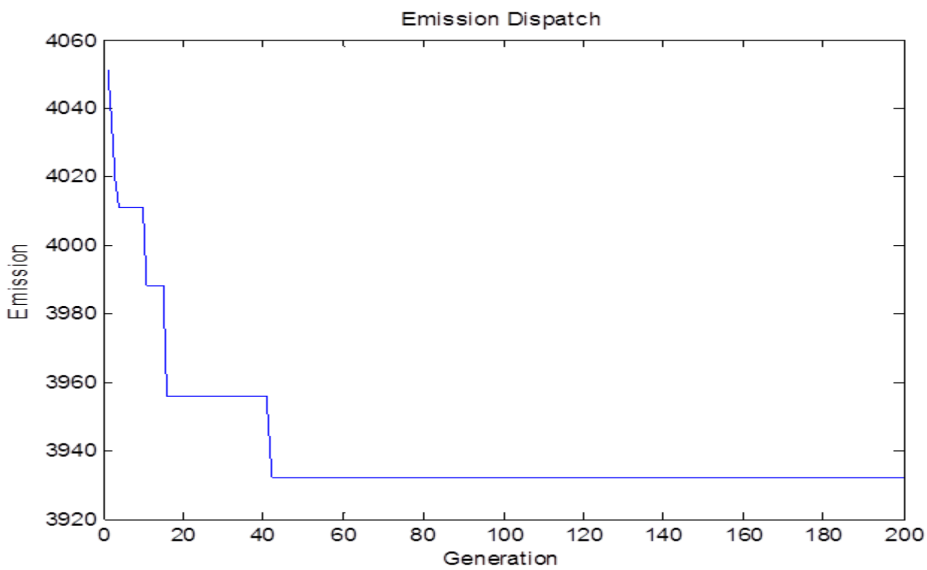


Fig 3.5-Convergence characteristic of EED for 10 units

<u>Table 3.6</u>–Combined Economic Emission dispatch for 10 generators system

Generator	CEED by GA
PG1	55
PG2	80
PG3	81.14
PG4	81.22
PG5	138.34
PG6	167.5
PG7	296.83
PG8	311.58
PG9	420.34
PG10	449.16
FUEL COST	113420
EMISSION	4120.1
Loss	88.23

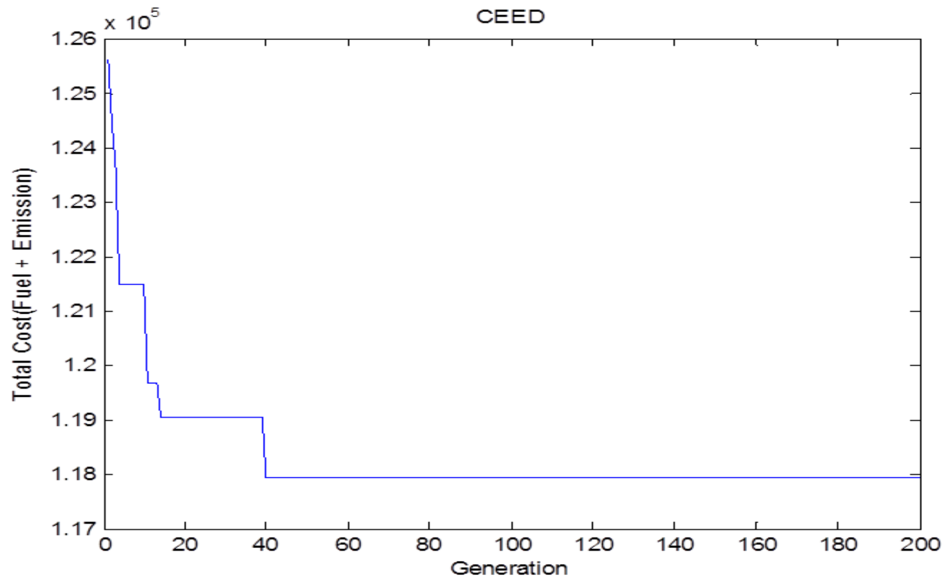


Fig 3.6-Convergence characteristic of CEED for 10 units

The results of solution ELD, EED and CEED by GA for 13 unit system are shown in Table 3.7, 3.8 and 3.9 respectively Fig 3.7-3.9 shows the convergence characteristics of ELD, EED and CEED for 13 unit system by GA

<u>Table 3.7</u>-Economic Load dispatch for 13 generators system

Generator	**Economic load dispatch by GA**
PG1	628.31
PG2	149.6
PG3	222.74
PG4	109.87
PG5	109.87
PG6	109.87
PG7	109.87
PG8	60
PG9	109.87
PG10	40
PG11	40
PG12	55
PG13	55
FUEL COST	17960.345
EMISSION	461.48

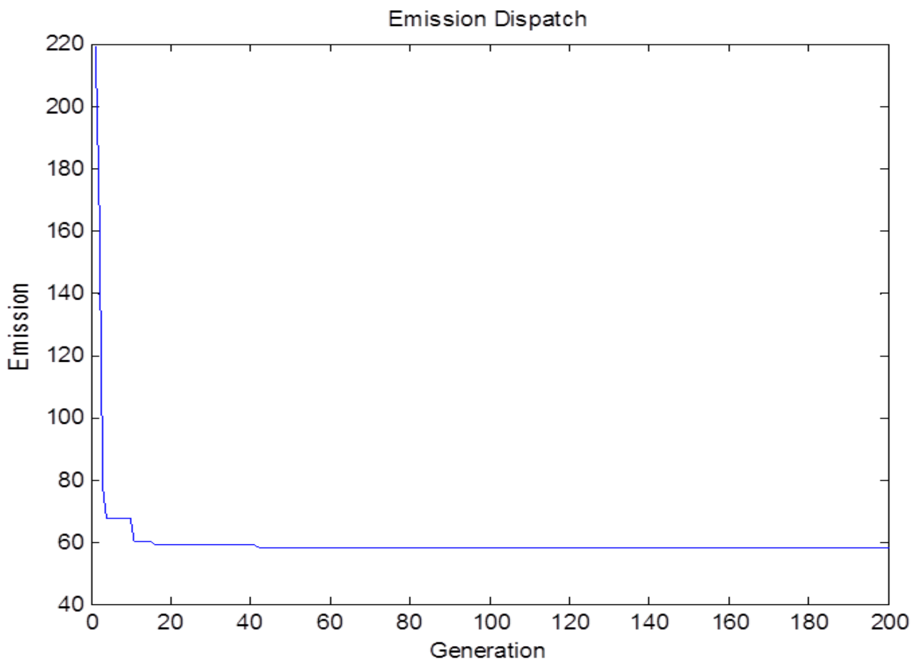


Fig3.7-Convergence characteristic of ELD for 13units

Table 3.8-Economic Emission dispatch for 13 generators system

Generator	Emission dispatch by GA
PG1	80.77
PG2	166.31
PG3	166.88
PG4	154.77
PG5	155.42
PG6	154.87
PG7	154.72
PG8	154.52
PG9	154.76
PG10	119.43
PG11	119.29
PG12	109.20
PG13	109.12
FUEL COST	19098.76
EMISSION	58.24

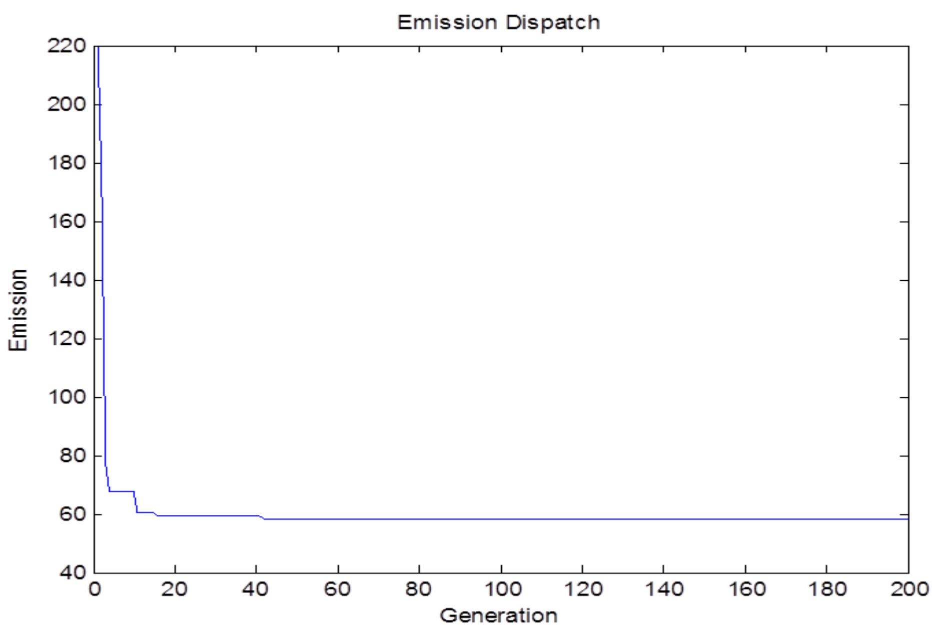


Fig 3.8-Convergence characteristic of EED for 13units

Table 3.9–Combined Economic Emission dispatch for 13 generators system

Generator	CEED
PG1	179.5
PG2	299
PG3	297.6
PG4	159.733
PG5	159.733
PG6	159.733
PG7	159.733
PG8	60
PG9	60
PG10	40
PG11	114.76
PG12	55
PG13	55
FUEL COST	18081.48
EMISSION	95.31

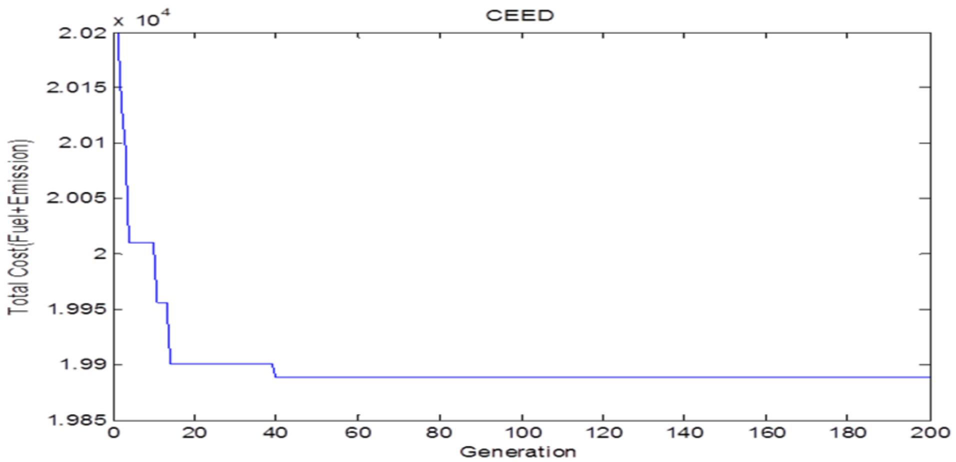


Fig 3.9-Convergence characteristic of CEED for 13units

3.7 Conclusion:

GENETIC ALGORITHIM is tried in IEEE-30 bus system with 6 nos of generators (case 1), 10 generators (case2), 13 generators (case 3). It has been found from the Table 3.3,3.6 & 3.9 that the fuel cost and emission evaluated by GA for CEED are 616. 01 and 0.2044 respectively for 6 units, 133420 & 4120.1 for 10 units and 18081.40 & 95.31 for 13 units The convergence characteristics fig 3.1 to fig 3.9also depict comparative information of the number of iterations required to converge in different cases.

Table 3.10-Summery

		FUEL COST	**EMISSION**	
6 UNITS		**GA**	**GA**	**No of iteration**
	ECONOMIC LOAD DISPATCH	602.47	0.2291	43
	ECONOMIC EMISSION DISPATCH	648.04	0.1942	36
	COMBINED ECONOMIC EMISSION DISPATCH	616.01	0.2044	56
10 UNITS	ELD	111500	4571.2	41
	E E D	116420	3932.3	40
	CEED	113420	4120.1	39
13 UNITS	ELD	17960.345	461.4.8	45
	E E D	19098.76	58.24	42
	CEED	18081.48	95.31	40

CHAPTER 4

Solution of combined economic emission dispatch by TLBO

4.1 Introduction

All of the evolutionary programming -based algorithms are probabilistic in nature and require some controlling parameters, like the population size, number of generations, etc. In addition to these control parameters, some algorithm-specific tuning -parameters are required. For example, GA uses the mutation rate and crossover rate. Similarly, PSO uses the inertia weight and cognitive parameters. The proper tuning of these parameters is an important factor and it affects the performance of the algorithms. The improper tuning of these parameters either increases the computational effort or yields a local optimal solution. On the other hand Teaching learning based optimization is a simple robust algorithm which is also population based but does not require any tuning parameter There is no burden of tuning control parameters in the TLBO algorithm and hence the TLBO algorithm is simple, effective and involves comparatively less computational effort

4.2 Teaching Learning based Optimization

The Teaching Learning based optimization was first proposed by R.V Rao for solving constrained optimization problems. The method was based on the influence of a teacher on learners. To explain the method let us assume that there are two different teachers T1 and T2 who teach same subject to two different classes of learners with same merit level. Fig 1 shows the distribution of marks obtained by the learners of two different classes as evaluated by teachers T1 and T2. The teacher tries to impart knowledge among learners, which will in turn increase the knowledge of the whole class and help learners to get good marks. So a teacher increases the mean of the class according to his or her capability. In fig. 4.1, teacher T1 will try to move mean M1 according to his or her capability, thereby increasing the level of learners to a new mean M2. Students will gain knowledge according to the quality of teacher r and the quality of students present in the class. The quality of the students is judged from the mean value of the population. Teacher T1 tries to increase the quality of the students from M1to M2, at which stage the students require a new teacher, i.e., in this case the new teacher is T2. Hence, there will be a new curve-2 with new teacher T2. For TLBO, the population is considered as a group of learners. In optimization algorithms, the population consists of different design variables. In analogous to different subjects offered to learners and the learners' result is analogous to the 'fitness', as in other population-based optimization techniques.

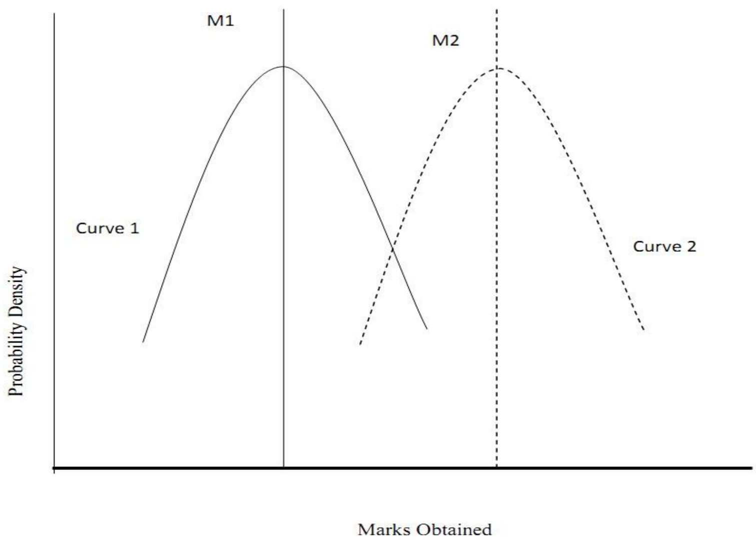


Fig. 4.1- distribution of marks obtained by learner of two different classes

For any iteration *i*, let there are 'm' number of subjects (i.e. design variables), 'n' number of learners (i.e., population size, k=1, 2, …, n) and $M_{j,\ i}$ be the mean result of the learners in a particular subject (j=1, 2, …, m).The population is randomly initialized within certain limit according to the equation

$$X_{i,j}^{0} = X_j^{min} + rand * (X_j^{max} - X_j^{min}) \tag{4.1}$$

Where rand denotes uniformly distributed random variable within the range (0,1), X_j^{min} , X_j^{max}= minimum and maximum value of jth parameter

The TLBO algorithm consists of two phases

i) "TEACHER PHASE"

ii) "LEARNER PHASE"

Teacher Phase:

In this phase learners learn from the teacher and improve their knowledge, which in turn, improves the mean result of the class.

The mean parameter of each subject of the learners in the class at generator g is given by

$$M^g = [m_1^g, m_2^g, - - - - - m_j^g - - - - m_D^g]$$

To obtain a new population set of learners

$$Xnew_i^g = X_i^g + rand(X_{Teacher}^g - T_F * M^g) \tag{4.2}$$

T_F=Teaching factor between value 1to 2

If $X_{new\ i}^g$ is better than X_i^g in generation g then it replace X_i^g otherwise it remains X_i^g

Learner Phase

The students can enhance their knowledge in Learner Phase by interacting with other students or by sharing knowledge

For a LearnerX_i^g

Another learner X_r^g is randomly selected with i≠r

Now to set a new vector in learner phase

$$Xnew_i^g = X_i^g + rand * \left(X_i^g - X_r^g\right) \, if \, f(X_i^g) < f(X_r^g) \tag{4.3}$$

$$Xnew_i^g = X_i^g + rand * \left(X_r^g - X_i^g\right) if \, f(X_i^g) > f(X_r^g) \tag{4.4}$$

The algorithm stops if number of iterations reaches the maximum number of iterations.

4.3 Application of TLBO to solve CEED

The sequential steps involved in solution of CEED by TLBO are explained below

Step 1: Input the total number of learners, number of subjects offered to the learners, cost coefficients, loss coefficients, load demand and limits of the constraints. Here the number of learners in a class is considered as population and the number of subjects offered to the learner is considered as generators. Each learner indicates a solution for the power generation of the units.

Step 2: Generate the initial population which satisfies the limits and constraints. Each individual (generating units' output) learner is randomly initialized according to equation (1) in the feasible range, which would satisfy the equality and inequality constraints. If any individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process of initialization until all constraints are satisfied.

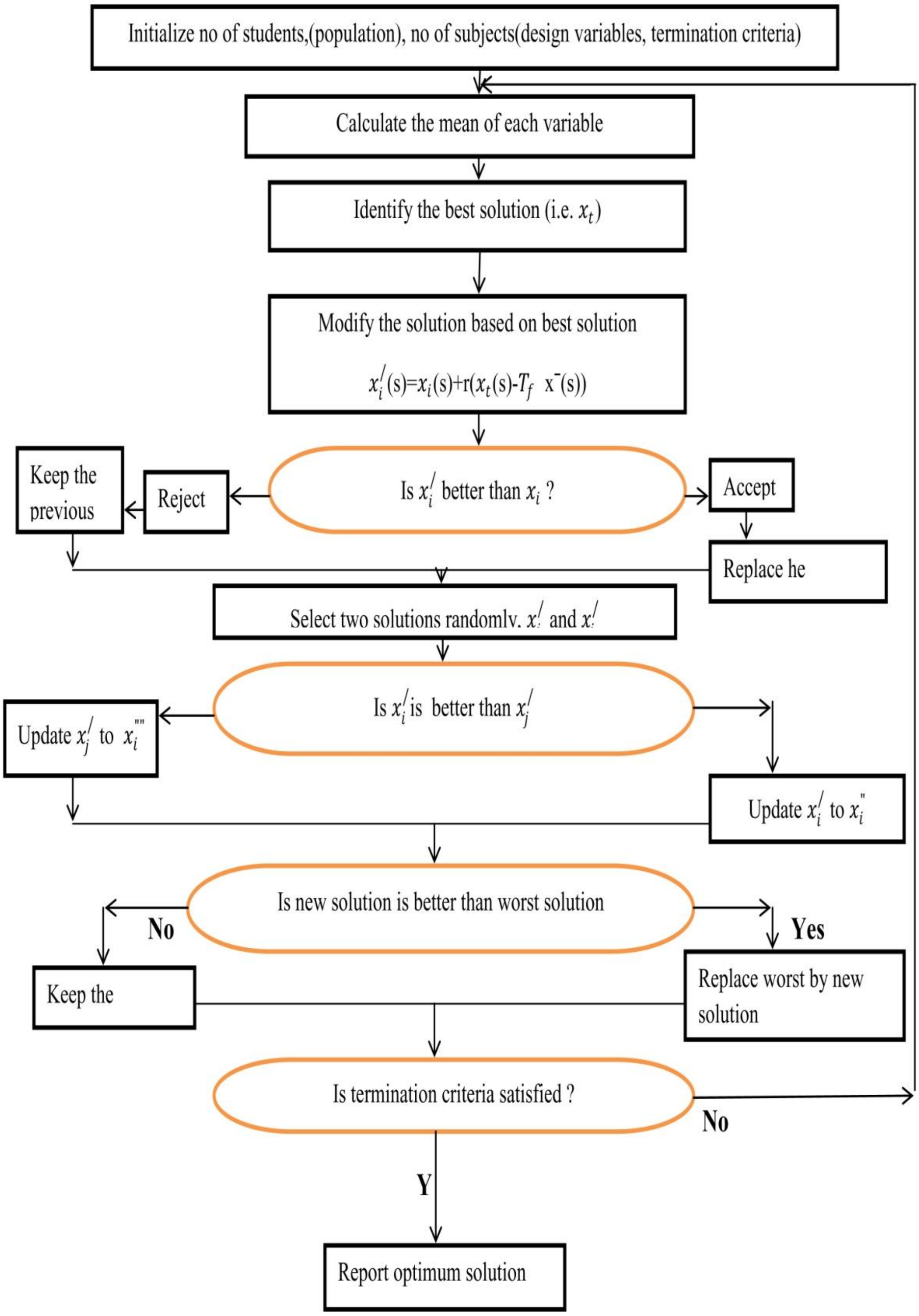
Step 3: Objective function of each individual is calculated.

Step 4: In the current iteration the best solution is considered as the teacher and the new value of population is calculated using equations (2) If any new individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 5: New learners are evaluated according to equation (5) and (6). If any new individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 6: Stop the process if maximum number of iteration is reached, otherwise repeat from step

4.4. Flowchart of TLBO algorithm



4.5 Results and Discussion

The proposed TLBO algorithm is applied to solve ELD, EED and CEED for three different test cases**.**

Test case 1: 6 unit system

Test case 2: 10 unit System

Test case 3: 13 unit System

4.5.1 Test case 1

The results of solution ELD, EED and CEED by TLBO for 6 unit system are shown in Table 4.1, 4.2 and 4.3 respectively. Results from GA are also shown in the table for comparison. Observation shows that fuel cost for ELD is 602.406 $ and Emission for EED is 0.194 lb and fuel cost and emission for CEED are 616.001 $ and 0.2044 lb. It has been observed, by TLBO a slightly better result has been attained.. Also the numbers of iterations needed in all the cases in TLBO are much less than that required in GA. Fig 4.2 -4.4 shows the comparison of fuel cost in ELD, emission in EED and fuel cost in CEED as obtained by TLBO and GA. Fig 4.5-4.7 shows the convergence characteristics of ELD, EED and CEED for 6 unit system by TLBO.

Table 4.1-Economic load dispatch by GA and TLBO for 6 units

Generator	**Economic load dispatch by GA**	**Economic load dispatch by TLBO**
PG1	0.1183	0.129
PG2	0.3068	0.298
PG3	0.4650	0.455

PG4	1.1025	1.122
PG5	0.5463	0.52
PG6	0.3012	0.314
FUEL COST	602.47	602.406
EMISSION	0.2291	0.2302
Loss	0.0533	0.054
Number of iteration	36	23

Table 4.2-Economic Emission Dispatch by GA and TLBO for 6 units

Generator	**Economic Emission dispatch by GA**	**Economic Emission dispatch by TLBO**
PG1	0.418	0.411
PG2	0.465	0.477
PG3	0.543	0.548
PG4	0.407	0.384
PG5	0.531	0.548
PG6	0.52	0.518
FUEL COST	649.04	651.14
EMISSION	0.1942	0.194
Loss	0.038	0.037
Number of iteration	36	25

Table 4.3- Combined Economic Emission Dispatch by GA and TLBO for 6 units

Generator	**CEED by GA**	**CEED by TLBO**
PG1	0.193	0.259
PG2	0.34	0.281
PG3	0.48	0.632
PG4	0.71	0.724
PG5	0.693	0.592
PG6	0.449	0.381
FUEL COST	616.01	616.001
EMISSION	0.2044	0.2044
Loss	0.044	0.043
Number of iteration	41	34

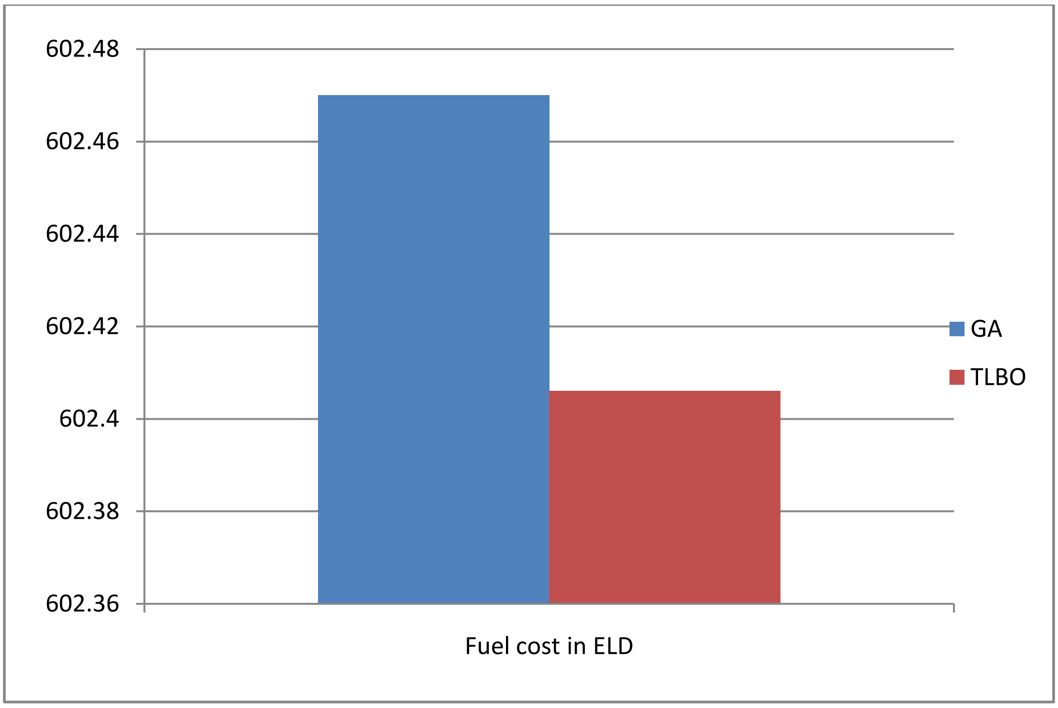


Fig. 4.2 Comparison of fuel cost in ELD by GA and TLBO

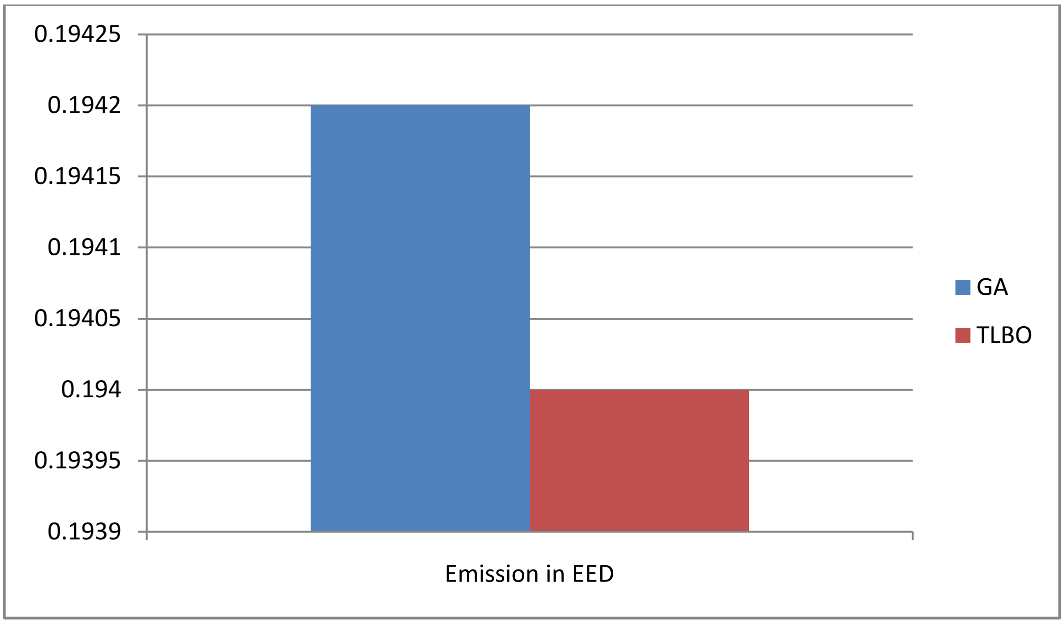


Fig. 4.3Comparison of emission in EED by GA and TLBO

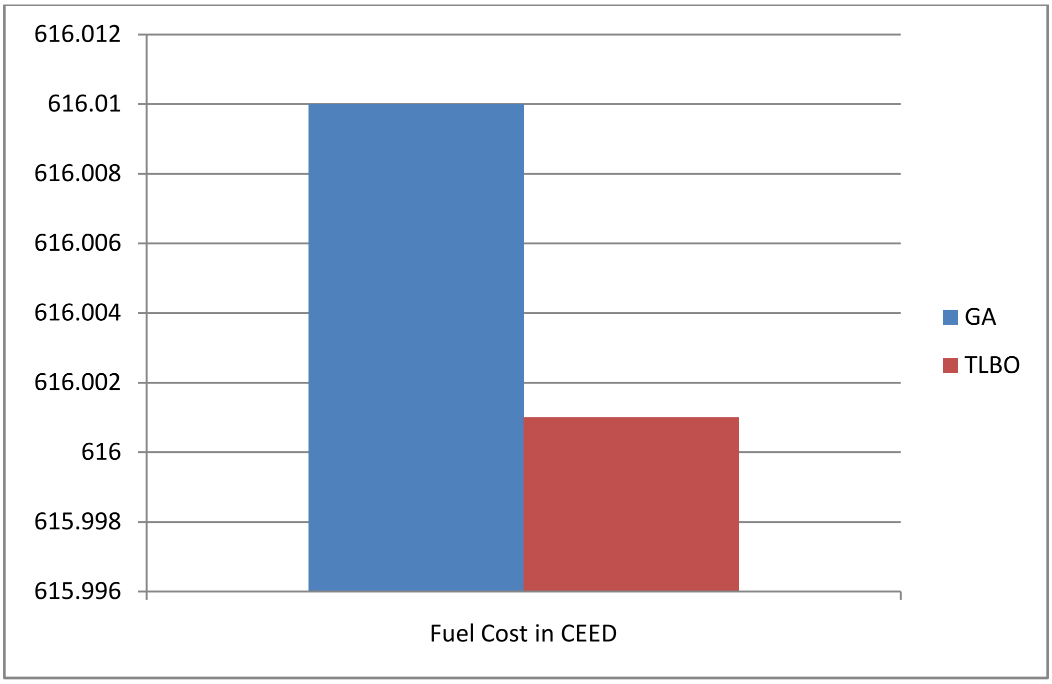


Fig. 4.4 Comparison of fuel cost in CEED by TLBO and GA

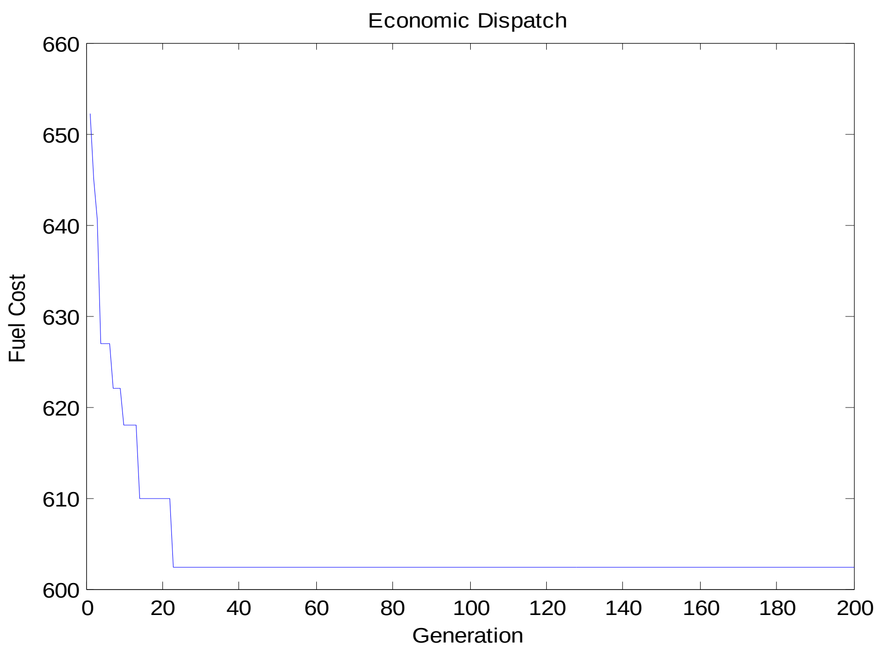


Fig. 4.5 Convergence characteristics of ELD for 6 unit system by TLBO

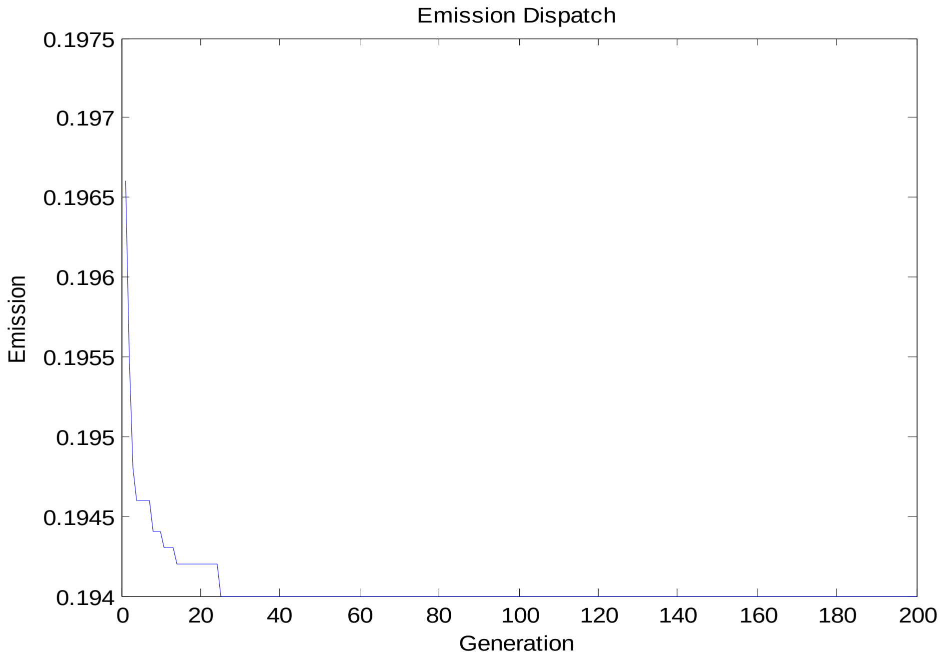


Fig. 4.6 Convergence characteristics of EED for 6 unit system by TLBO

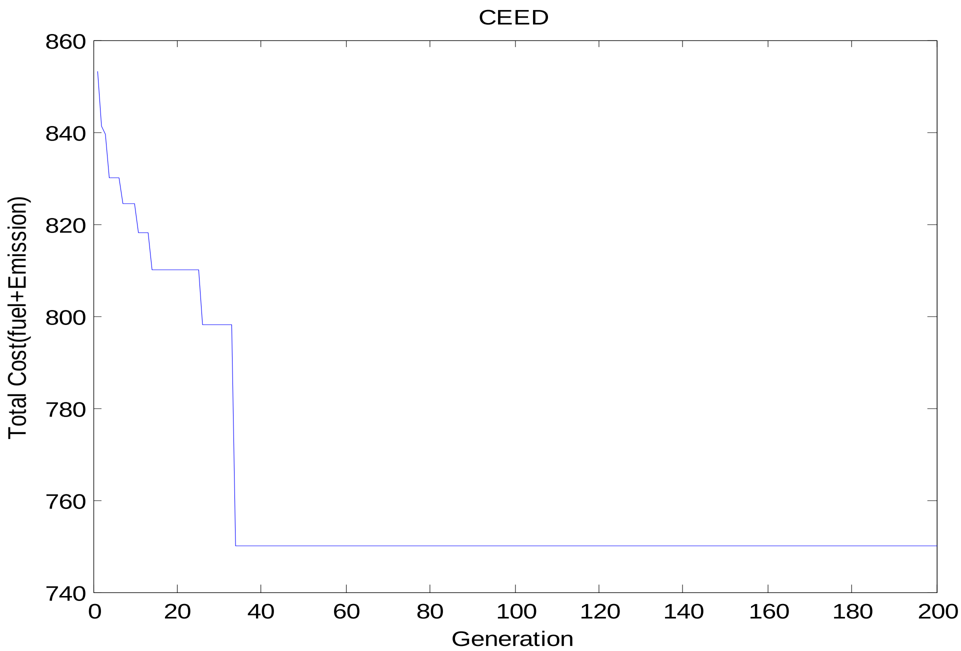


Fig. 4.7 Convergence characteristics of CEED for 6 unit system by TLBO

4.5.2 Test case 2

The results of solution ELD, EED and CEED by TLBO for 10 unit system are given in Table 4.4,4.5 and 4.6 respectively. Results obtained by using GA are also shown in the table for comparison observations show that fuel cost for ELD is 111497.632$ and Emission for EED is 3932.243 lb and fuel cost and emission for CEED are 113106.894$ and 4150.496 lb. It has been observed that, in terms of objective functional slight better results has been obtained by TLBO as compared to GA except for emission in CEED. Also the numbers of iterations required in all the cases in TLBO are much less than that needed in GA. Fig 4.8 - 4.11 shows the comparison of fuel cost in ELD, emission in EED and fuel cost in CEED, emission in CEED as obtained by TLBO and GA. Fig 4.12-4.14 shows the convergence characteristics of ELD, EED and CEED for 10 unit system by TLBO.

Table 4.4 Economic Load Dispatch by GA and TLBO for 10units

Generator	Economic load dispatch by GA	Economic load dispatch by TLBO
PG1	55	55
PG2	80	79.999
PG3	106.93	106.946
PG4	100.57	100.607
PG5	81.49	81.478
PG6	83.01	83.007
PG7	300	299.999
PG8	340	339.999
PG9	470	469.999
PG10	470	469.999
FUEL COST	111500	111497.632
EMISSION	4571.2	4572.362
Loss	87.03	87.03
Number of iteration	41	14

Table 4.5 Economic Emission Dispatch by GA and TLBO for 10 units

Generator	Economic Emission dispatch by GA	Economic Emission dispatch by TLBO
PG1	55	55
PG2	80	80
PG3	81.96	81.134
PG4	78.82	81.363
PG5	160	160
PG6	240	240
PG7	300	294.485
PG8	292.78	297.27
PG9	401.84	396.77
PG10	391.21	395.576
FUEL COST	116420	116412.443
EMISSION	3932.3	3932.243
Loss	81.59	81.595
Number of iteration	40	17

Table 4.6 Combined Economic Emission Dispatch by GA and TLBO for 10 units

Generator	CEED by GA	CEED by TLBO
PG1	55	54.888
PG2	80	79.96
PG3	81.14	86.586
PG4	81.22	83.74
PG5	138.34	134.27
PG6	167.5	157.134
PG7	296.83	297.64
PG8	311.58	217.295
PG9	420.34	440.48
PG10	449.16	432.23
FUEL COST	113420	113106.894
EMISSION	4120.1	4150.496
Loss	84.17	83.223
Number of iteration	39	17

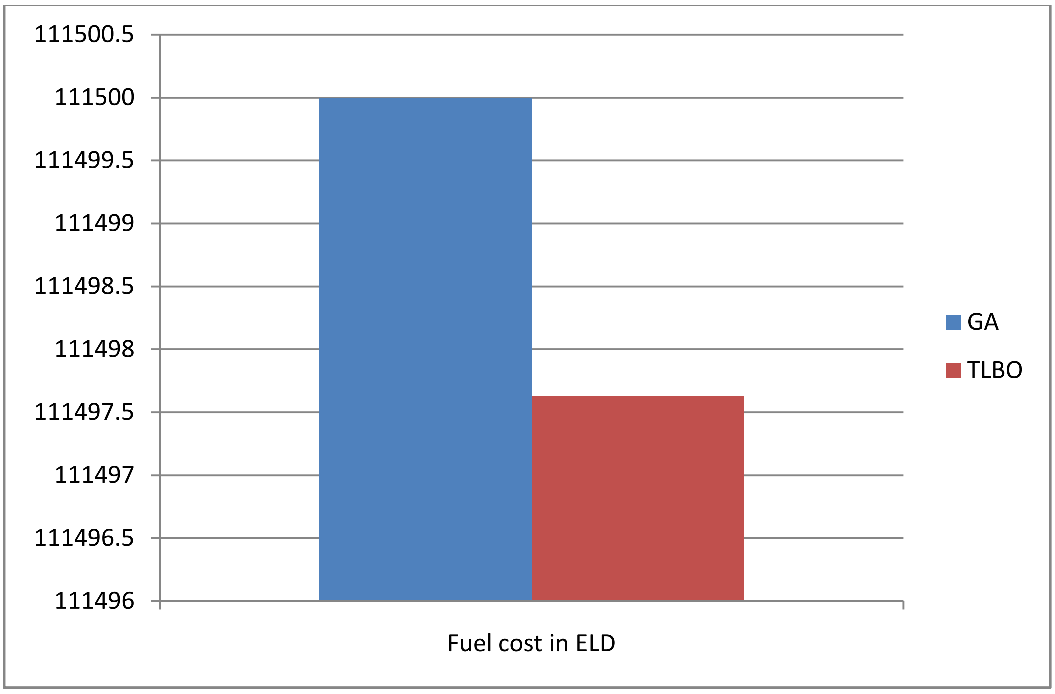


Fig. 4.8Comparison of fuel cost in ELD by GA and TLBO

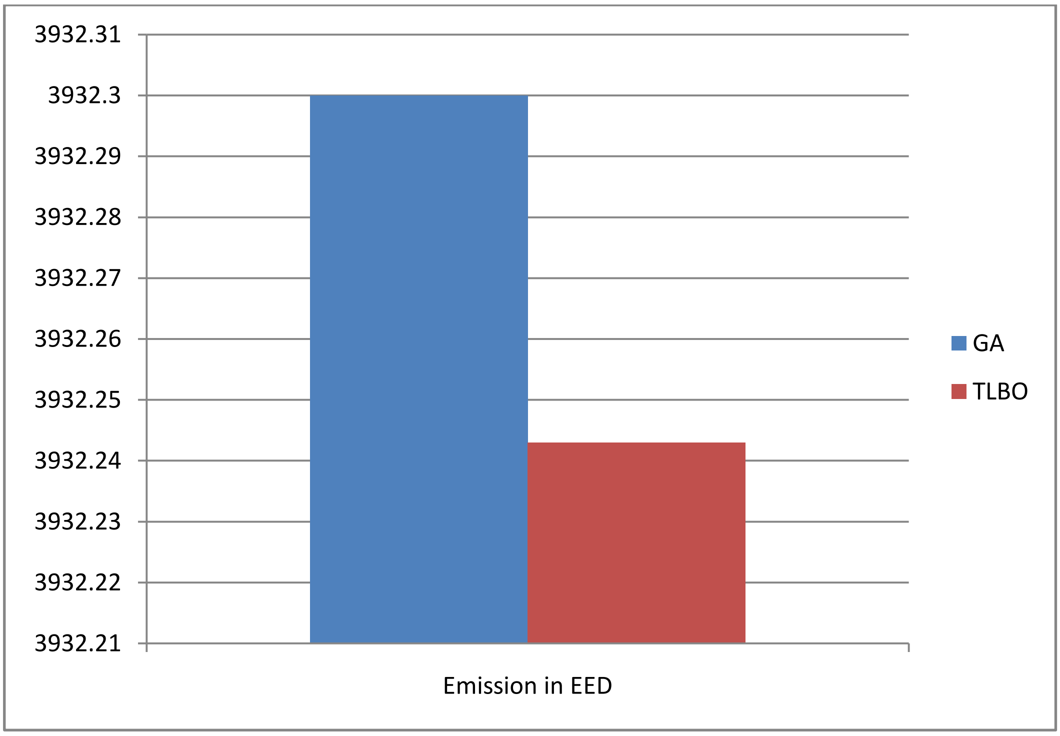


Fig. 4.9 Comparison of emission in EED by GA and TLBO

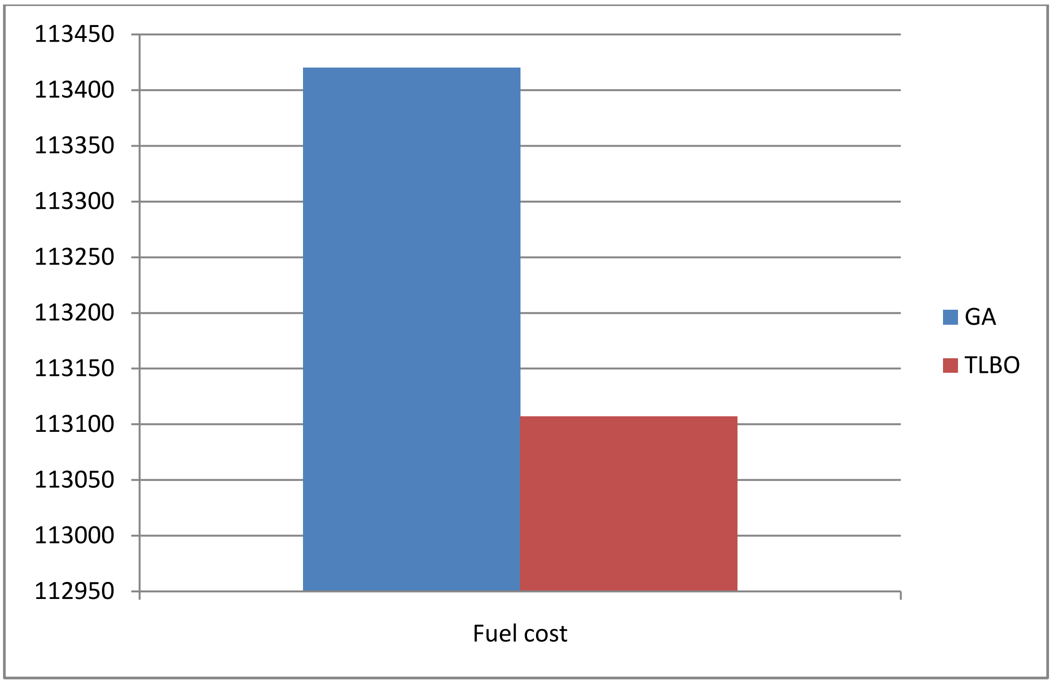


Fig. 4.10 Comparison of fuel cost in CEED by GA and TLBO

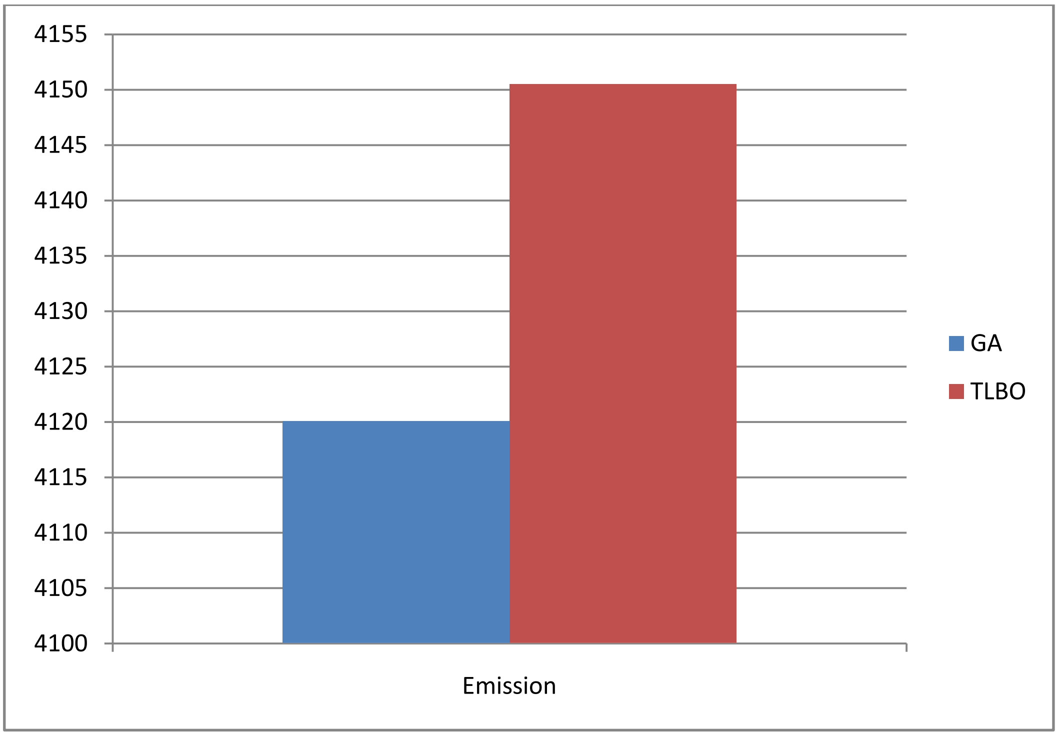


Fig. 4.11Comparison of emission in CEED by GA and TLBO

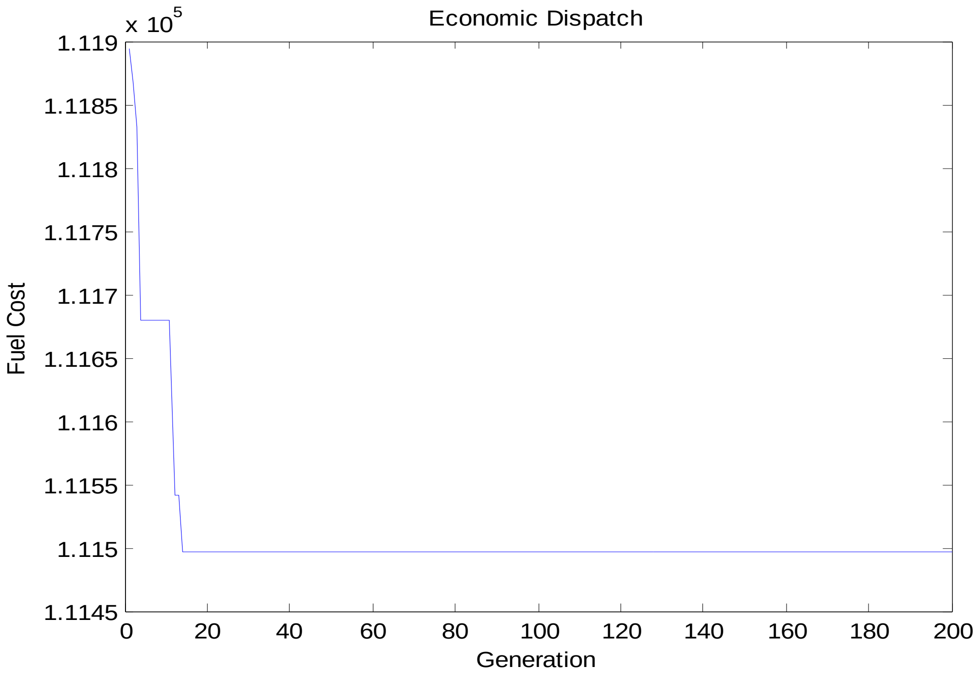


Fig 4.12-Convergence characteristic of ELD by TLBO for 10 unit system

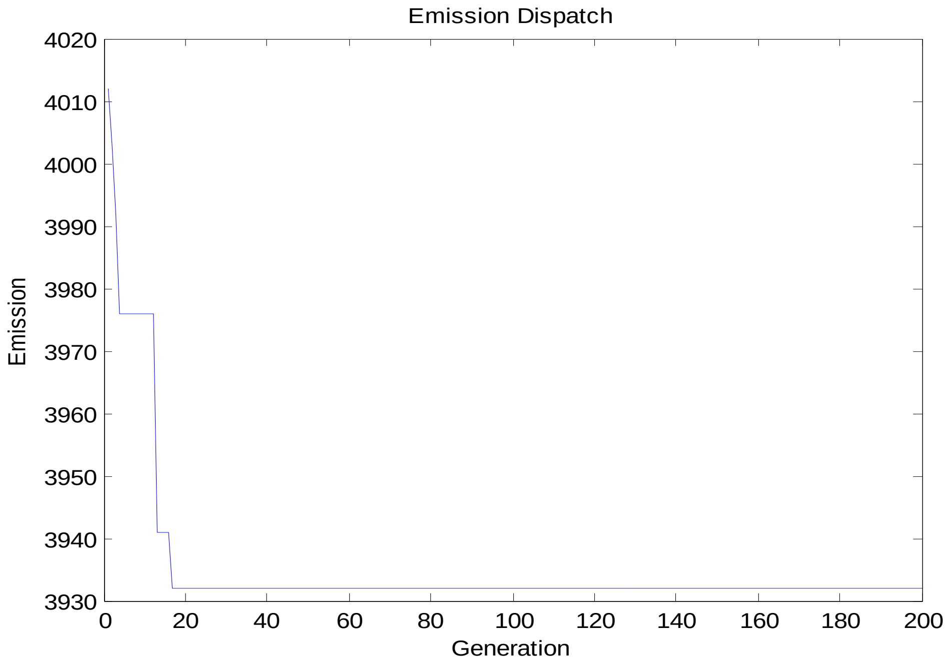


Fig 4.13-Convergence characteristic of EED by TLBO for 10 unit system

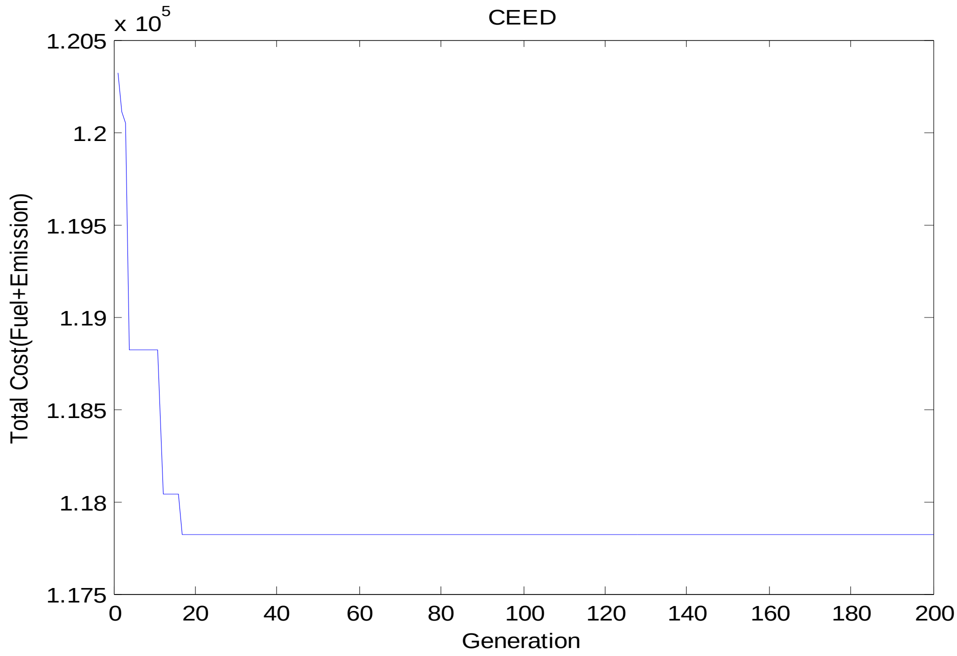


Fig 4.14-Convergence characteristic of CEED by TLBO for 10 unit system

4.5.3 Test case 3

The results of solution ELD, EED and CEED by TLBO for 13 unit system are given in Table 4.7, 4.8and 4.9 respectively. Results monitored byapplying GA are also shown in the table for comparison. From observation, fuel cost for ELD is found as 17396.83$ and Emission for EED is found as 58.24 lb and fuel cost and emission for CEED are 18047.063$ and 85.8 lb. A slight better results in terms of objective function has been observed by TLBO as compared to GA except for emission in CEED. Also the numbers of iterations required in all the cases in TLBO are much less than that needed in GA. Fig 4.15 -4.18 shows the comparison of fuel cost in ELD, emission in EED and fuel cost in CEED, emission in CEED as obtained by TLBO and GA. Fig 4,19- 4.21 shows the convergence characteristics of ELD, EED and CEED for 10 unit system by TLBO.

Table 4.7 Economic Load Dispatch by GA and TLBO for 13 units

Generator	Economic load dispatch by GA	Economic load dispatch by TLBO
PG1	628.31	628.32
PG2	149.6	222.75
PG3	222.74	149.6
PG4	109.87	109.87
PG5	109.87	60
PG6	109.87	109.87
PG7	109.87	109.87
PG8	60	109.87
PG9	109.87	109.87
PG10	40	40
PG11	40	40
PG12	55	55
PG13	55	55
FUEL COST	17963.845	17963.83
EMISSION	461.48	461.48
Number of iteration	45	23

Table 4.8 Economic Emission Dispatch by GA and TLBO for 13 units

Generator	Economic Emission dispatch by GA	Economic Emission dispatch by TLBO
PG1	179.5	80.64
PG2	299	166.33
PG3	297.6	166.33
PG4	159.733	154.73
PG5	159.733	154.73
PG6	159.733	154.73
PG7	159.733	154.73
PG8	60	154.73
PG9	60	154.73
PG10	40	119.96
PG11	114.76	119.96
PG12	55	109.19
PG13	55	109.19
FUEL COST	18081.48	19145.57
EMISSION	95.31	58.24
Number of iteration	42	22

Table 4.9 Combined Economic Emission Dispatch by GA and TLBO for 13 units

Generator	CEED by GA	CEED by TLBO
PG1	80.77	179.20
PG2	166.31	224.73
PG3	166.88	299.21
PG4	154.77	159.61
PG5	155.42	109.87
PG6	154.87	159.72
PG7	154.72	159.64
PG8	154.52	159.74
PG9	154.76	158.04
PG10	119.43	40.01
PG11	119.29	40
PG12	109.20	55
PG13	109.12	55.11
FUEL COST	19098.76	18047.063
EMISSION	58.24	85.8
Number of iteration	40	22

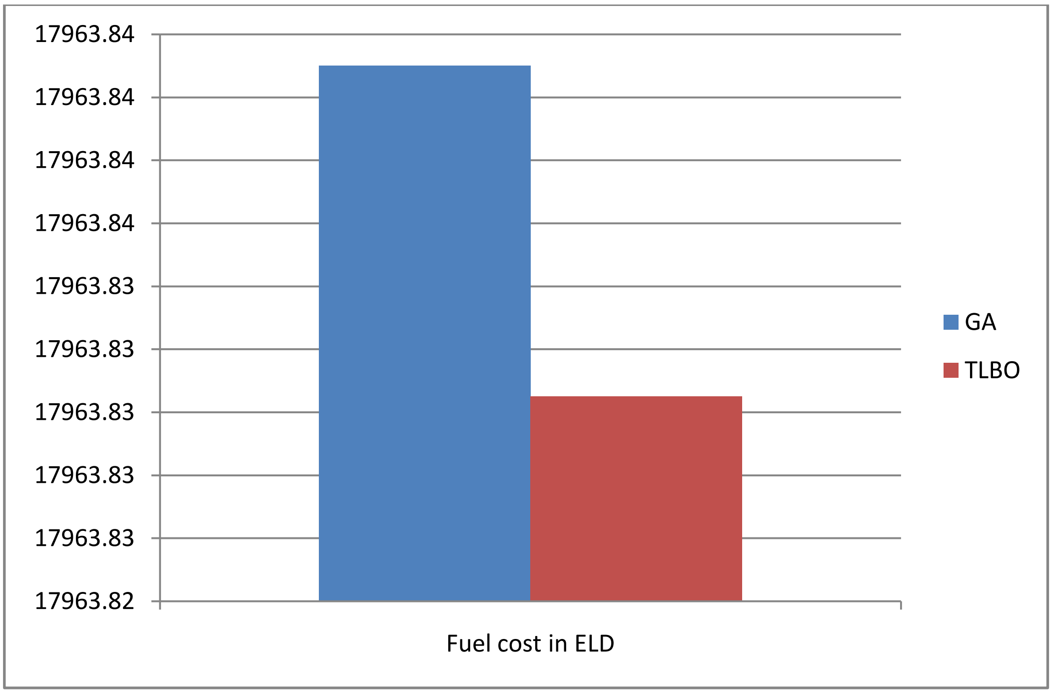


Fig 4.15Comparison of fuel cost in ELD by GA and TLBO

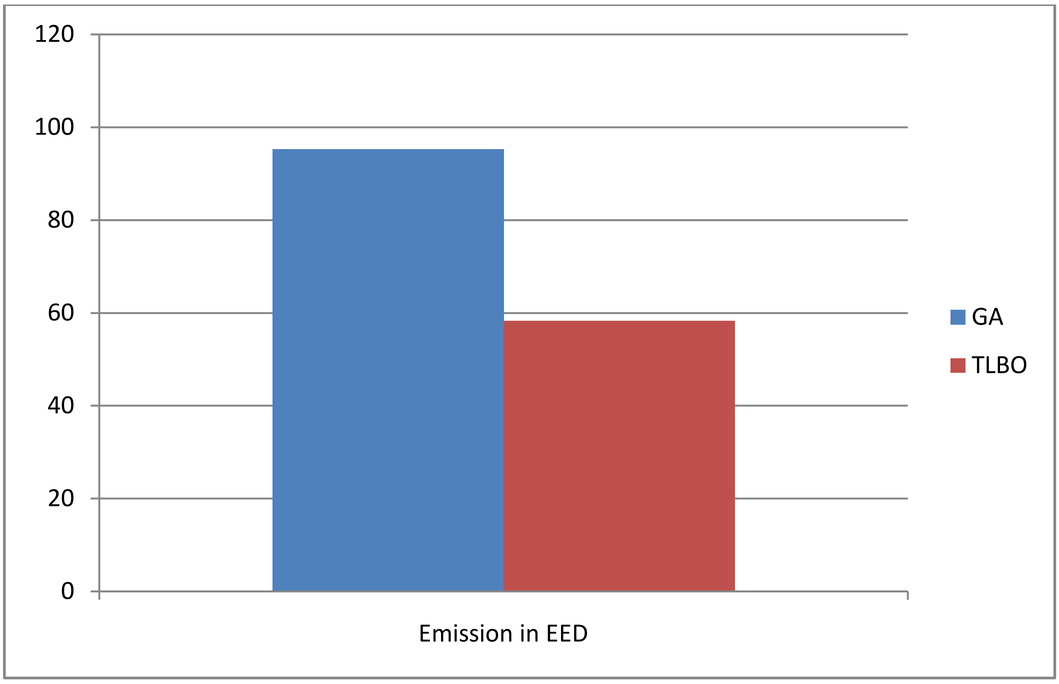


Fig 4.16 Comparison of Emission in EED by GA and TLBO

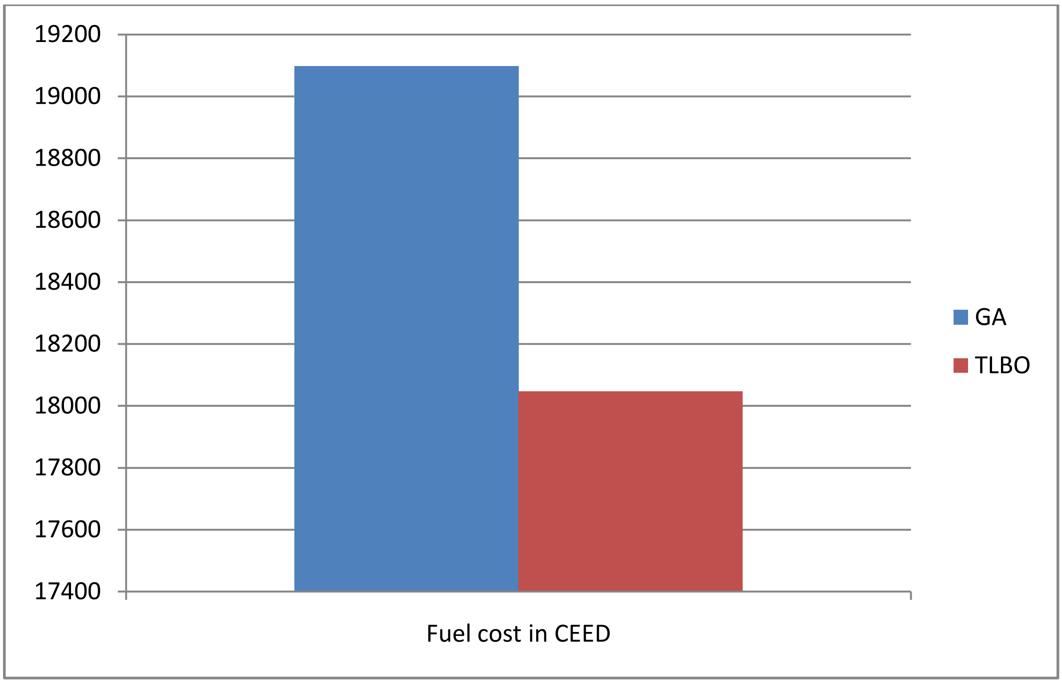


Fig 4.17 Comparison of Fuel cost in CEED by GA and TLBO

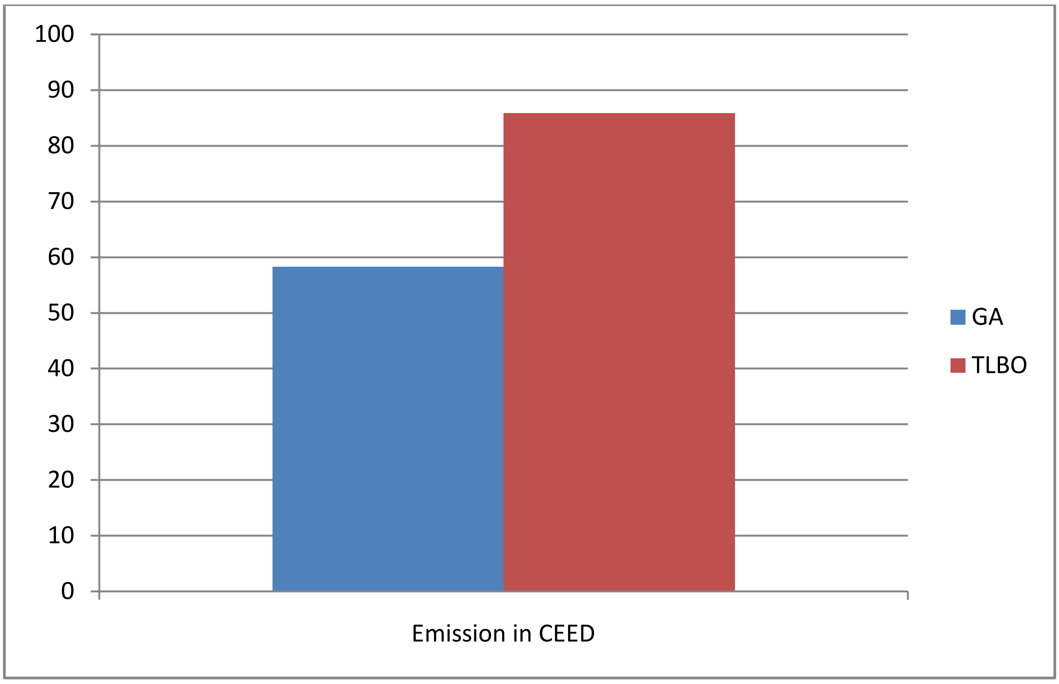


Fig 4.18 Comparison of Emission in CEED by GA and TLBO

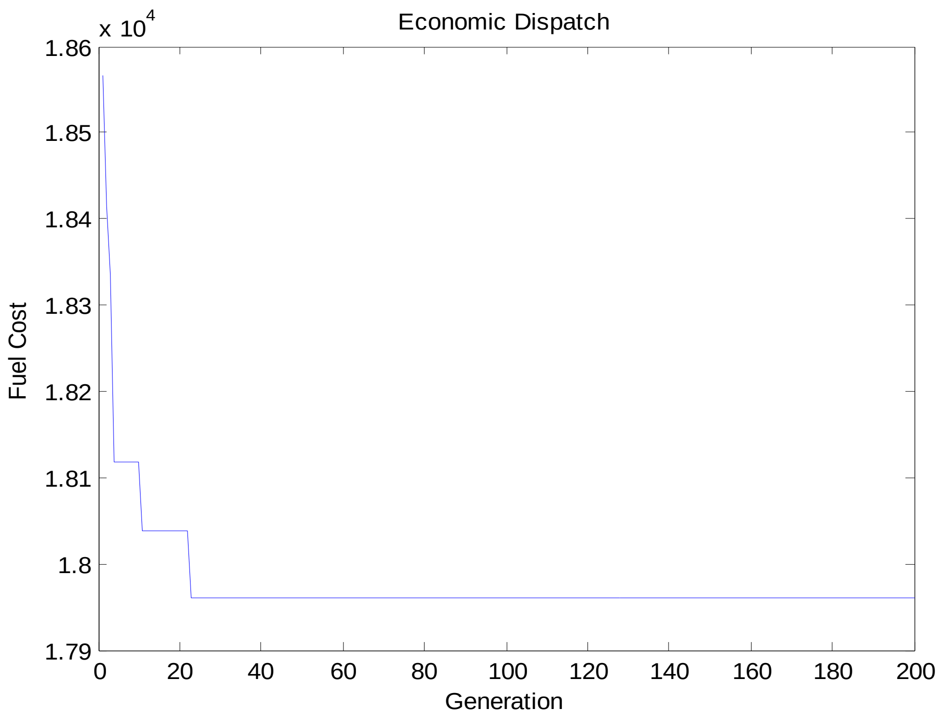


Fig 4.19 Convergence characteristic of ELD by TLBO for 13 unit system

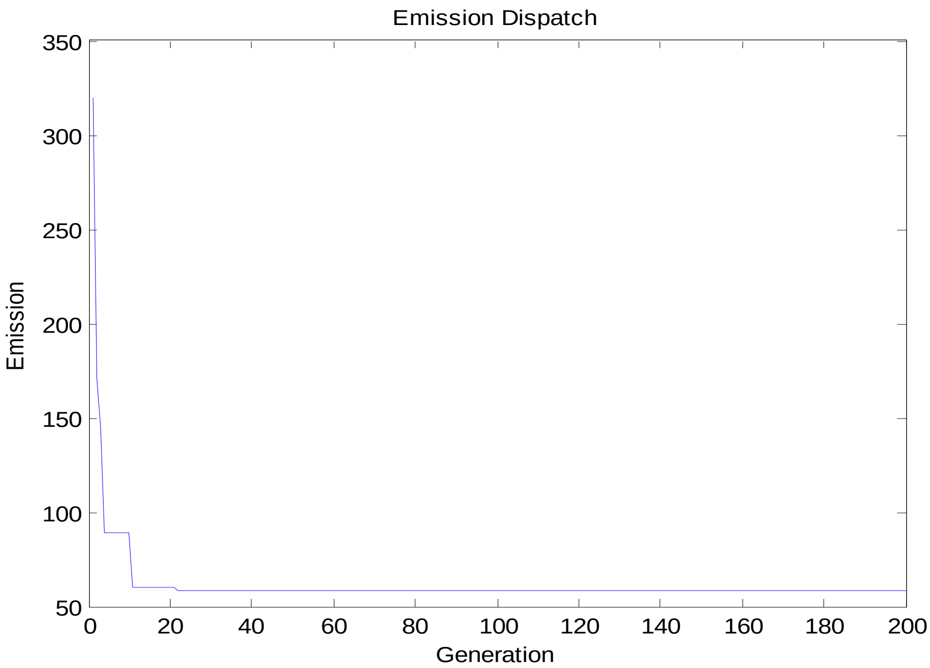


Fig 4.20 Convergence characteristic of EED by TLBO for 13 unit system

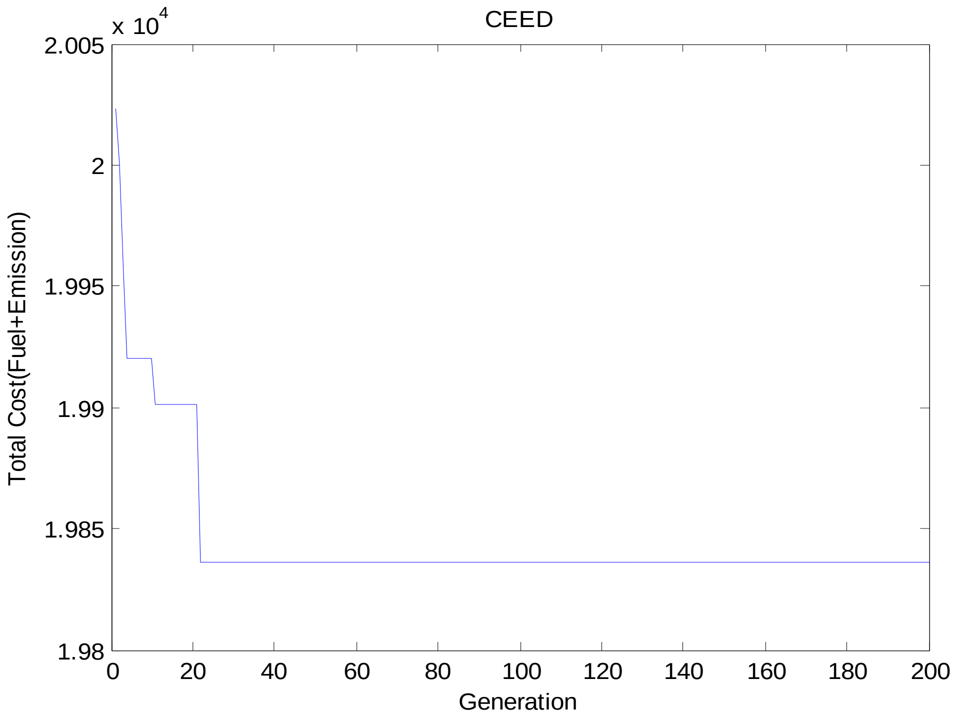


Fig 4.21 Convergence characteristic of CEED by TLBO for 13 unit system

4.6 Conclusion

The problems of ELD, EED as well as CEED are of great importance for power system engineers. In this chapter the problem of ELD, EED as well as CEED are solved by using TLBO. And the results of TLBO are compared with GA. This comparison clearly establishes that TLBO is superior over GA in terms of convergence criterion. Three test systems are taken into consideration and the problem of ELD, EED and CEED are solved for them to establish the efficacy of the algorithm. The establishment of inherent capability of TLBO for solving non linear, non convex problem is very much evident here. Also it is proved that the performance of TLBO is not affected by addition of non linearity. Thus conclusion can be drawn that TLBO is an efficient algorithm for solving real world complex problems.

CHAPTER 5

Solution of combined economic emission dispatch by hybrid GA-TLBO

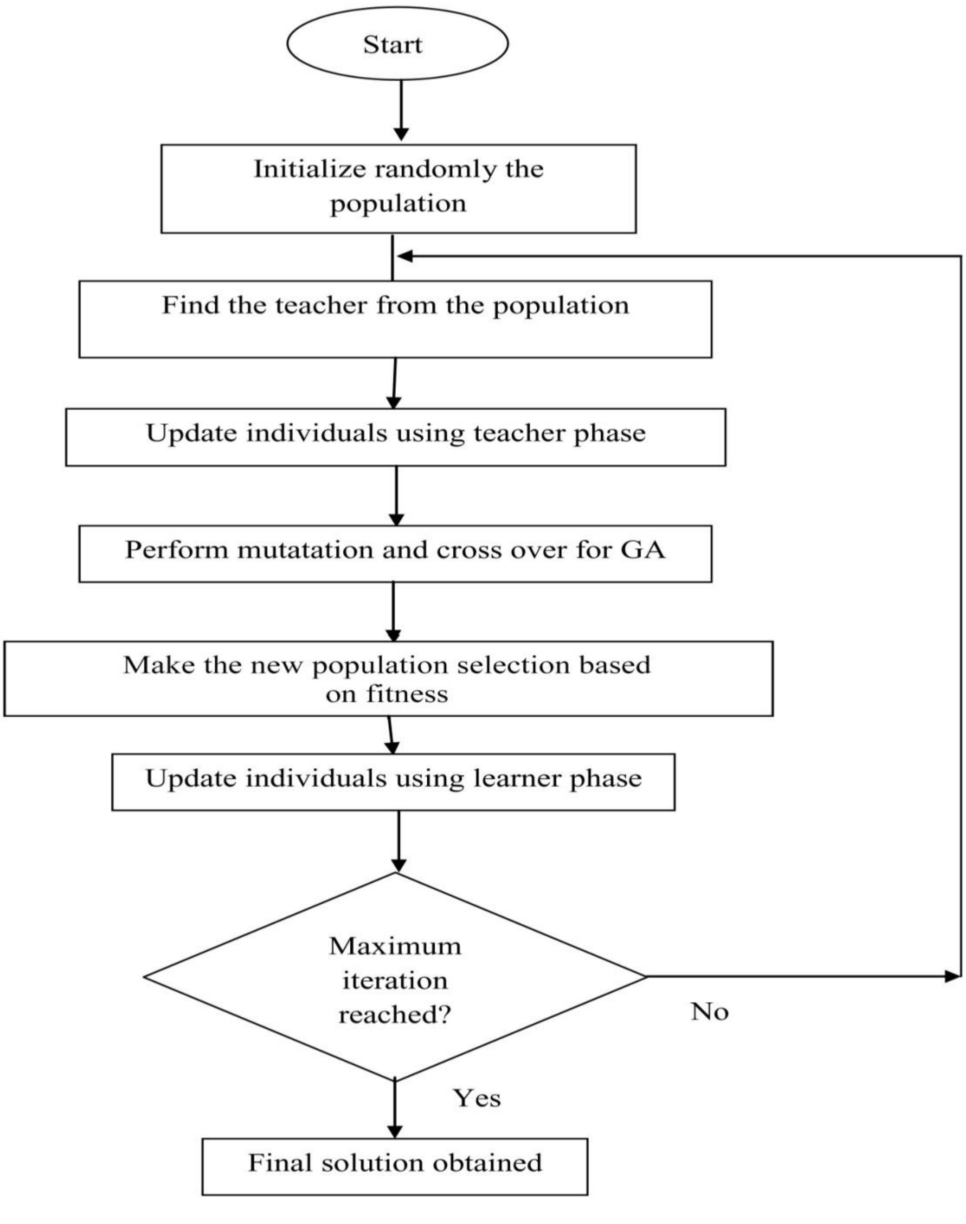
5.1 Introduction

The main objective of solving the combined economic emission dispatch problem in electric power system is to determine the generation levels for all on-line units which minimize the total fuel cost and the emission level of the system, while satisfying a set of constraints. Because of the complex and dynamic nature of CEED problem the use of evolutionary algorithms has attracted the interest of researchers. Because the performance of evolutionary methods are independent of the initial solutions and are derivative-free, they overcome the main limitations of classical optimization method. Evolutionary algorithms are easy to implement and can be combined with others. Therefore, most researchers have been inspired to combine two or more methods to offer an efficient hybrid optimization method. The core reason behind hybridization is to enhance the solution quality by overcoming the limitations of each technique. In this chapter a hybrid technique of optimization involving TLBO and SQP is developed and applied to solve CEED problem.

5.2 Overview of hybrid GA-TLBO algorithm

In this section a hybrid algorithm based on Genetic Teaching Learning-Based Optimization (G-TLBO) Algorithm is proposed. The proposed algorithm is combined of conventional TLBO Algorithm and conventional GA. Standard TLBO algorithm needs the best students at the beginning of the algorithm at each iteration. GA selects the best students for TLBO algorithm using chromosome coding, roulette, crossover and tournament GA works quicker than TLBO algorithm in selection of the best students because of its efficiency at reaching the global minimum points. The main reason to use the GA in the proposed algorithm is to determine the intermediate power values as much as possible for the TLBO algorithm so total algorithm runtime decreases substantially.

The following flowchart explains the hybrid GA-TLBO algorithm,



5.3 GA-TLBO applied to CEED

The steps involved in solution of CEED by GA-TLBO are as explained below

Step 1: Input the maximum number of iterations, mutation rate crossover rate, cost coefficients, loss coefficients, load demand and limits of the constraints and size of population.

Step 2: Generate the initial population which satisfies the limits and constraints.

Step 3: Objective function of each individual is calculated

Step 4: Update individuals of new population according to teacher phase. If any updated individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 5: Perform cross over and mutation.

Step 6: Check the constraints. If any new individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process of crossover and mutation until all constraints are satisfied.

Step 7: Make the selection based on objective function to produce new population.

Step 8: Update individuals according to learner phase. If any updated individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 9: Check for termination criteria. If the termination criterion is met stop, otherwise repeat from step 4.

5.4 Results and Discussion

The proposed TLBO algorithm is applied to solve ELD, EED and CEED for three different test cases**.**

Test case 1: 6 unit system

Test case 2: 10 unit System

Test case 3: 13 unit System

5.4.1 Test case 1

The results of solution ELD, EED and CEED by GA-TLBO for 6 unit system are given in Table 5.1, 5.2 and 5.3 respectively. Results obtained by TLBO are also shown for comparison. Table 5.1 depicts that the fuel cost in case of ELD for 6 unit system obtained by TLBO and GA-TLBO are 602.406$ and 602.404$ respectively which clearly reveals the fact that fusion of GA with TLBO gives better performance. Similar kind of result is observed for EED and CEED as well. Better performance is obtained in terms of convergence criterion and also as the number of iterations is less for GA- TLBO. Fig.5.1, Fig5..2, Fig.5.3 and Fig5..4 signifies the graphical representation of the results reported in table 5.1, table 5.2 and table 5.3. Fig.5.5, Fig.5.6 and Fig.5.7 represents the convergence criterion for ELD, EED and CEED.

Table 5.1 Economic Load Dispatch by TLBO and GA-TLBO for 6 units

Generator	**Economic load dispatch by TLBO**	**Economic load dispatch by GA-TLBO**
PG1	0.129	0.127
PG2	0.298	0.299
PG3	0.455	0.453
PG4	1.122	1.1175
PG5	0.52	0.5290
PG6	0.314	0.3146
FUEL COST	602.406	602.404
EMISSION	0.2302	0.2299
ITERATION	23	17

Table 5.2 Economic Emission Dispatch by TLBO and GA-TLBO for 6 units

Generator	**Economic Emission dispatch by TLBO**	**Economic Emission dispatch by GA-TLBO**
PG1	0.411	0.4099
PG2	0.477	0.4721
PG3	0.548	0.5456
PG4	0.384	0.3955
PG5	0.548	0.5387
PG6	0.518	0.5239
FUEL COST	651.14	650.05
EMISSION	0.194	0.1942
ITERATION	25	16

Table 5.3 Combined Economic Emission Dispatch by TLBO and GA-TLBO for 6 units

Generator	CEED by TLBO	CEED by GA-TLBO
PG1	0.259	0.255
PG2	0.281	0.361
PG3	0.632	0.636
PG4	0.724	0.743
PG5	0.592	0.479
PG6	0.381	0.39
FUEL COST	616.001	615.01
EMISSION	0.2044	0.204
ITERATION	34	19

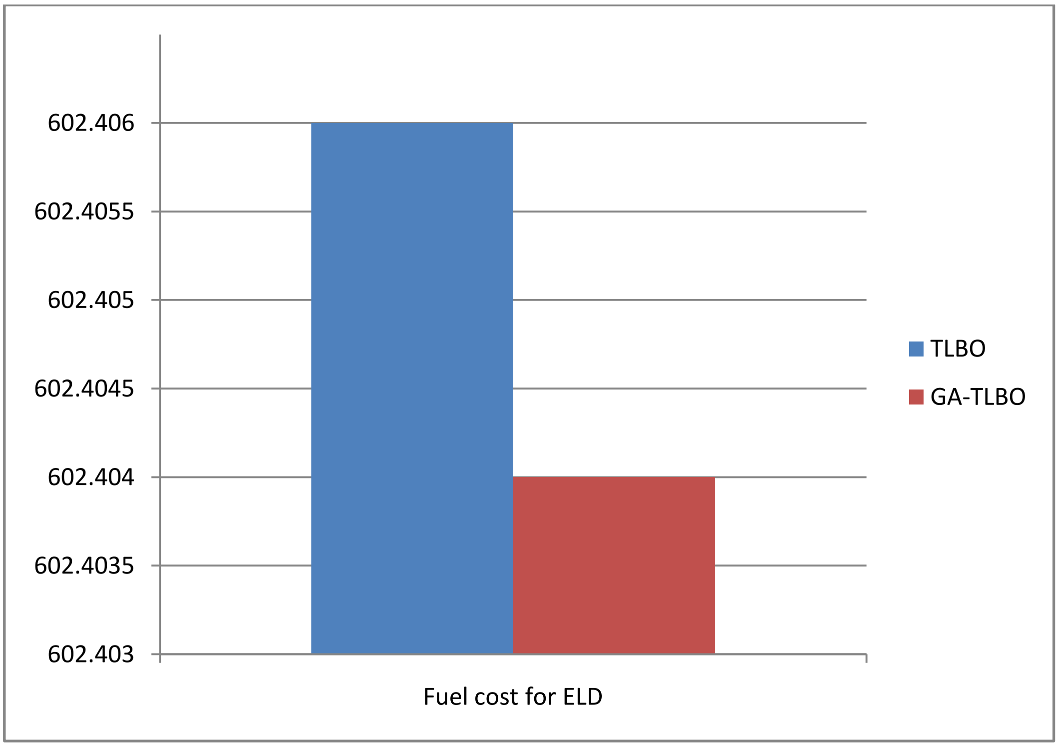


Fig 5.1 Comparison of fuel cost for ELD by TLBO, GA-TLBO

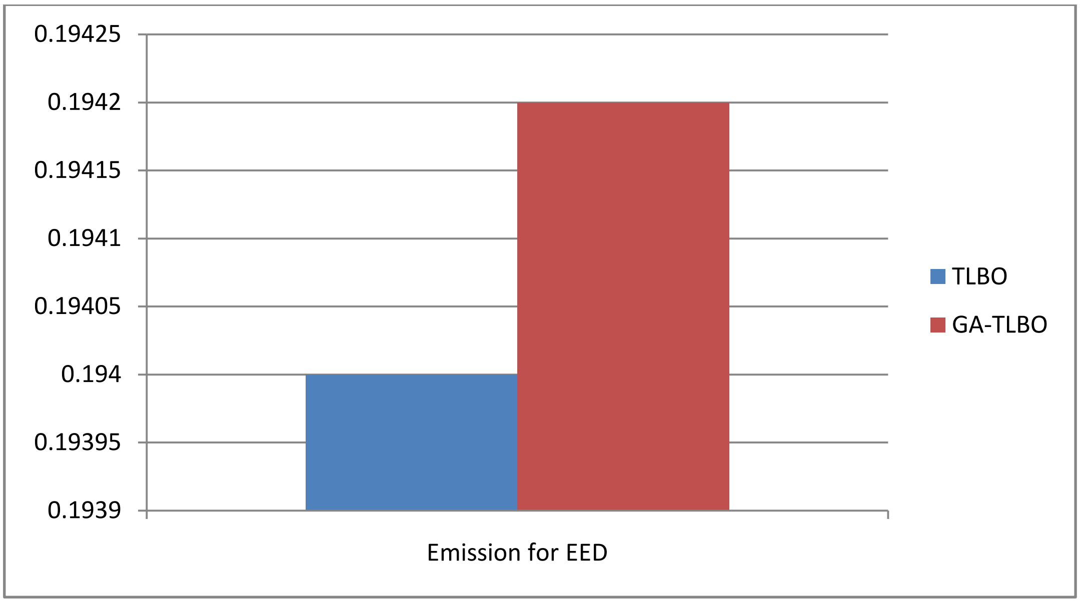


Fig 5.2 Comparison of emission for EED by TLBO, GA-TLBO

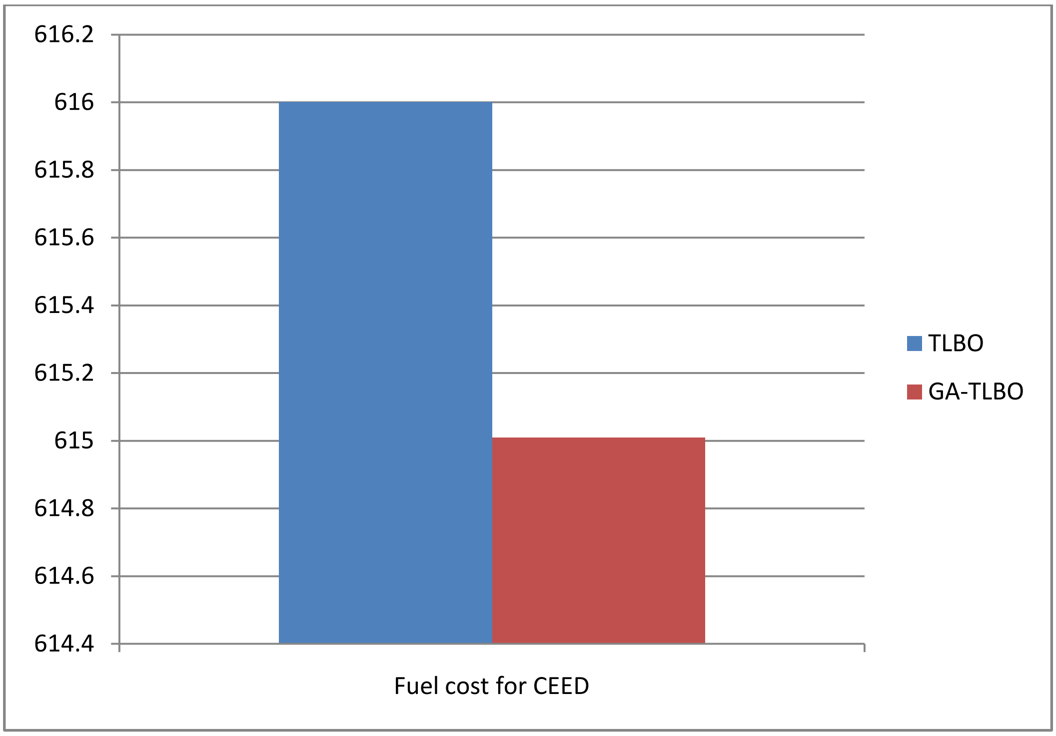


Fig 5.3 Comparison of fuel cost for CEED by TLBO, GA-TLBO

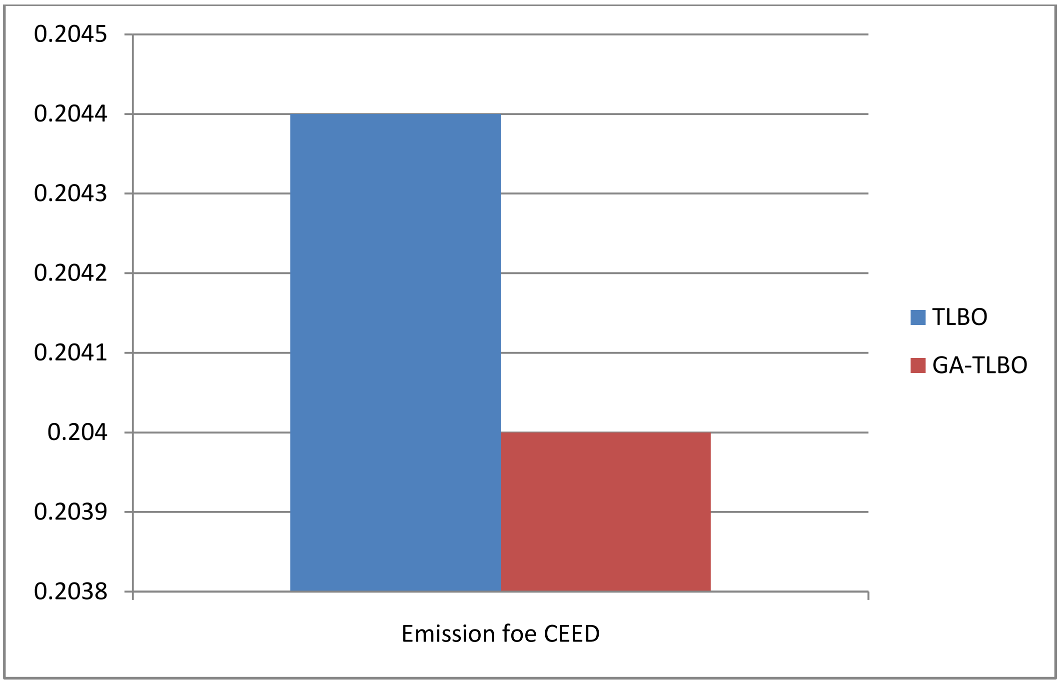


Fig 5.4 Comparison of emission for CEED by TLBO, GA-TLBO

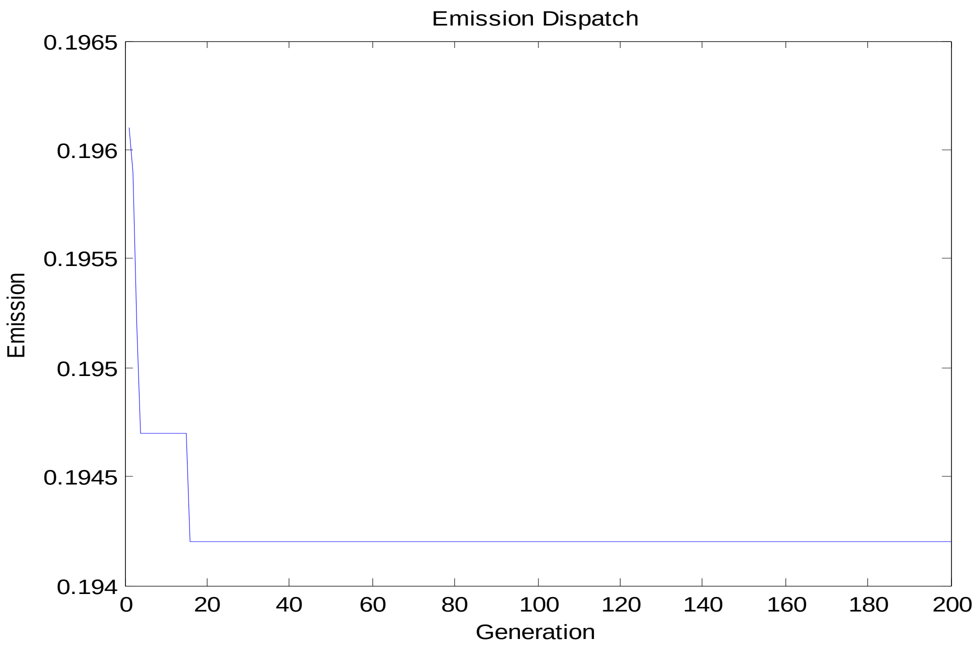


Fig.5.5- Convergence criterion for ELD for 6 units

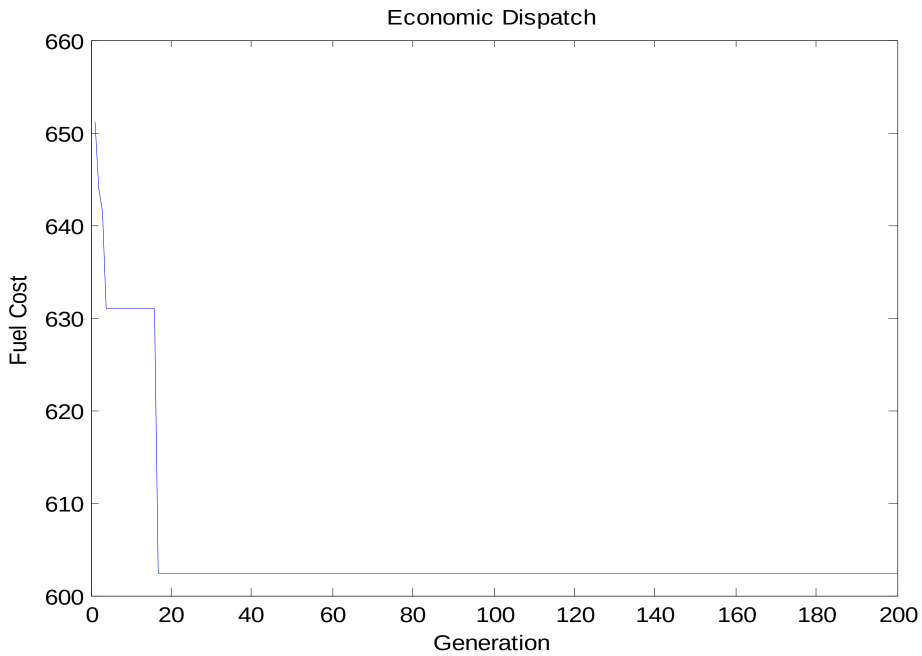


Fig5..6- Convergence criterion for EED for 6 units

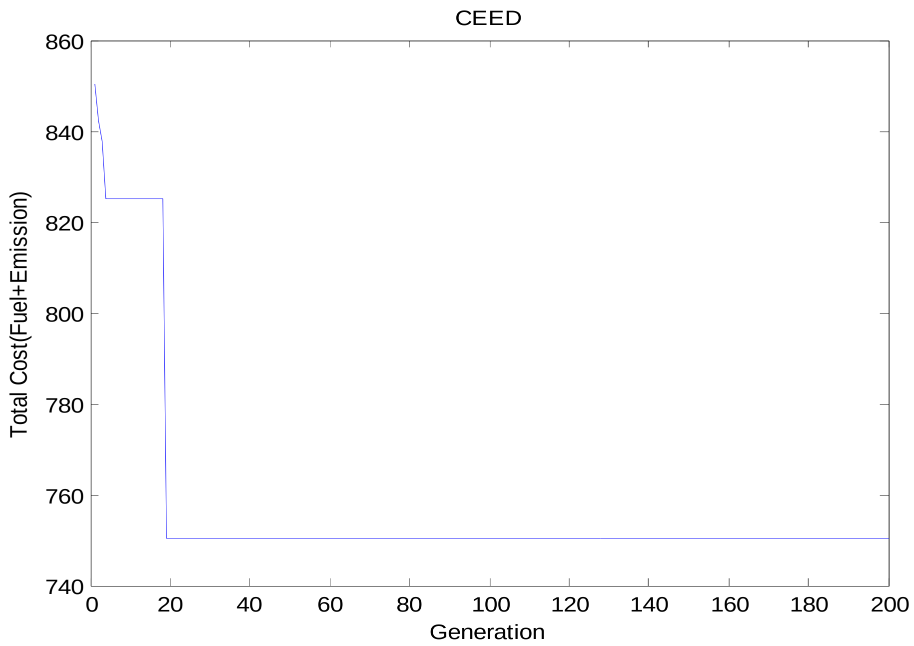


Fig.5.7- Convergence criterion for CEED for 6 units

5.4.2 Test case 2

The results of solution ELD, EED and CEED by GA-TLBO for 10 unit system are given in Table 5.4, 5.5 and 5.6 respectively. Results obtained by TLBO are also shown for comparison. Table 5.4 reports that the fuel cost in case of ELD for 6 unit system obtained by TLBO and GA-TLBO are 11497.632 $ and 108015$ respectively which clearly proves the fact that fusion of GA with TLBO gives better performance. Similar trend is observed for EED and CEED as well. Better performance is obtained in terms of convergence criterion and also the number of iterations is less for GA TLBO. Fig.5.8, Fig.5.9, Fig.5.10 and Fig.5.11 signifies the graphical representation of the results reported in table 5.4, table 5.5 and table 5.6 Fig.5.12, Fig.5.13and Fig.5.14 represents the convergence criterion for ELD, EED and CEED.

Table 5.4 Economic Load Dispatch by TLBO and GA-TLBO for 10 units

Generator	**Economic load dispatch by TLBO**	**Economic load dispatch by GA-TLBO**
PG1	55	40.5326
PG2	79.999	45.8383
PG3	106.946	115.7578
PG4	100.607	104.3776
PG5	81.478	104.7259
PG6	83.007	112.6931
PG7	299.999	285
PG8	339.999	252.21
PG9	469.999	470.00
PG10	469.999	470.00
FUEL COST	111497.632	108015.0
EMISSION	4572.362	4123.7
ITERATION	14	11

Table 5.5 Economic Emission Dispatch by TLBO and GA-TLBO for 10 units

Generator	Economic Emission dispatch by TLBO	Economic Emission dispatch by GA-TLBO
PG1	55	55
PG2	80	80
PG3	81.134	82.13
PG4	81.363	81.36
PG5	160	81.5
PG6	240	160
PG7	294.485	240
PG8	297.27	295.48
PG9	396.77	396.76
PG10	395.576	395.57
FUEL COST	116412.443	116512.44
EMISSION	3932.243	3932.24
ITERATION	17	12

Table 5.6 Combined Economic Emission Dispatch by TLBO and GA-TLBO for 10 units

Generator	CEED by TLBO	CEED by GA-TLBO
PG1	54.888	46.49749
PG2	79.96	75
PG3	86.586	75.37136
PG4	83.74	63.07534
PG5	134.27	99.64559
PG6	157.134	240.0000
PG7	297.64	227
PG8	217.295	340.0090
PG9	440.48	470.0000
PG10	432.23	364.9724
FUEL COST	113106.894	110421.605
EMISSION	4150.496	3922.49
ITERATION	17	11

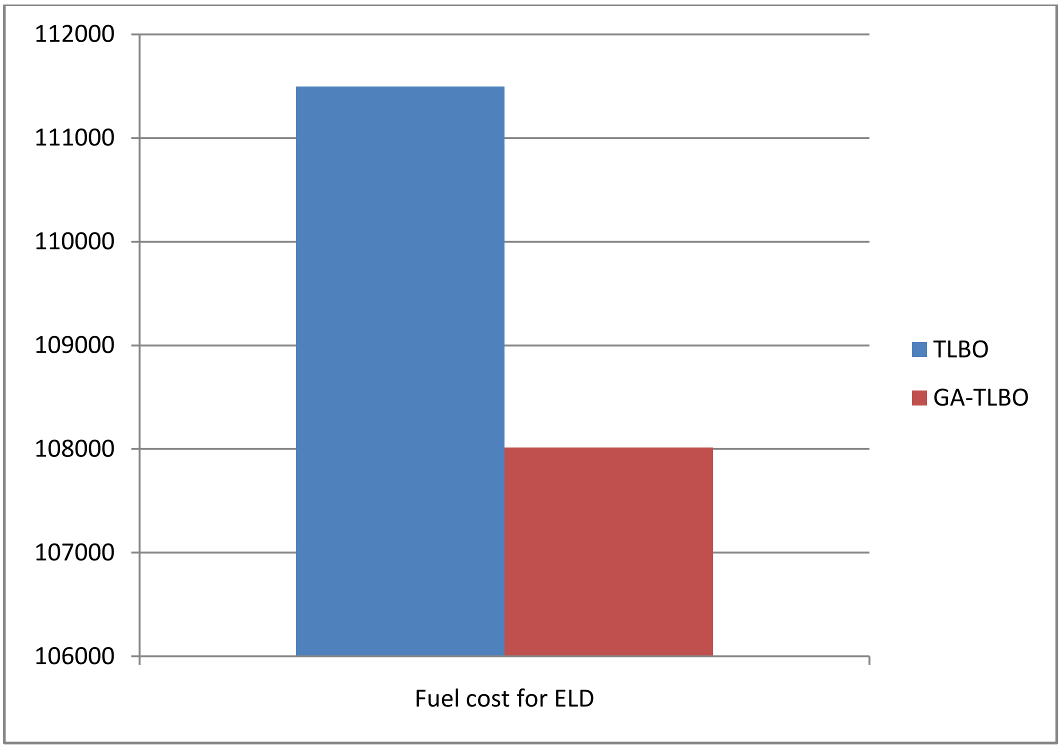


Fig 5.8 Comparison of fuel cost for ELD by TLBO, GA-TLBO

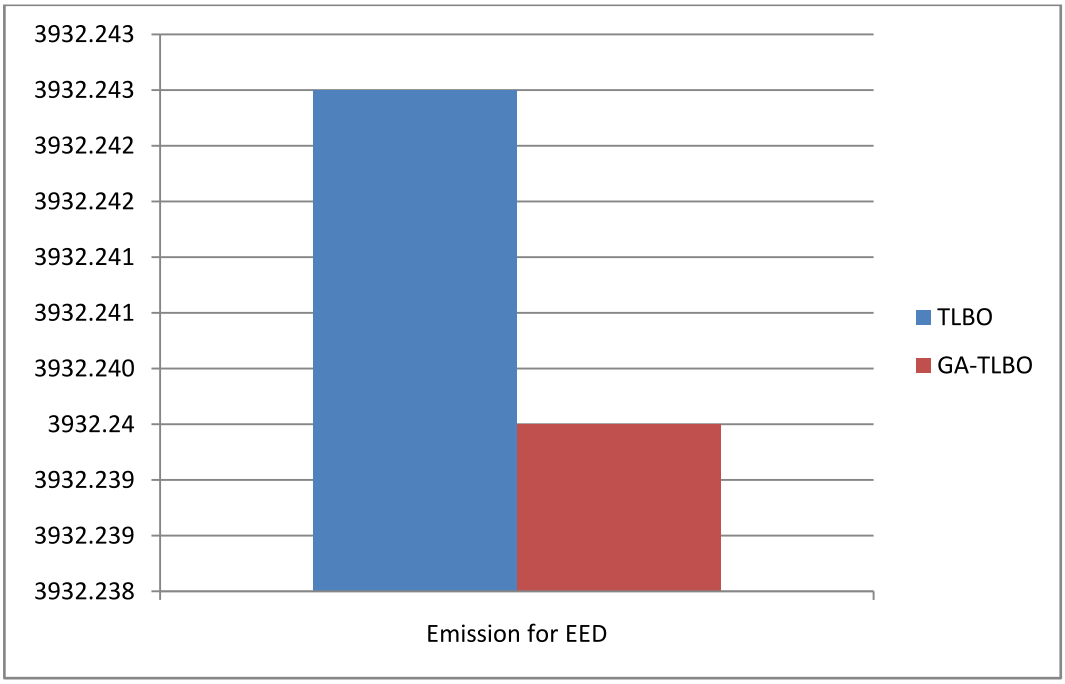


Fig5.9 Comparison of Emission for EED by TLBO, GA-TLBO

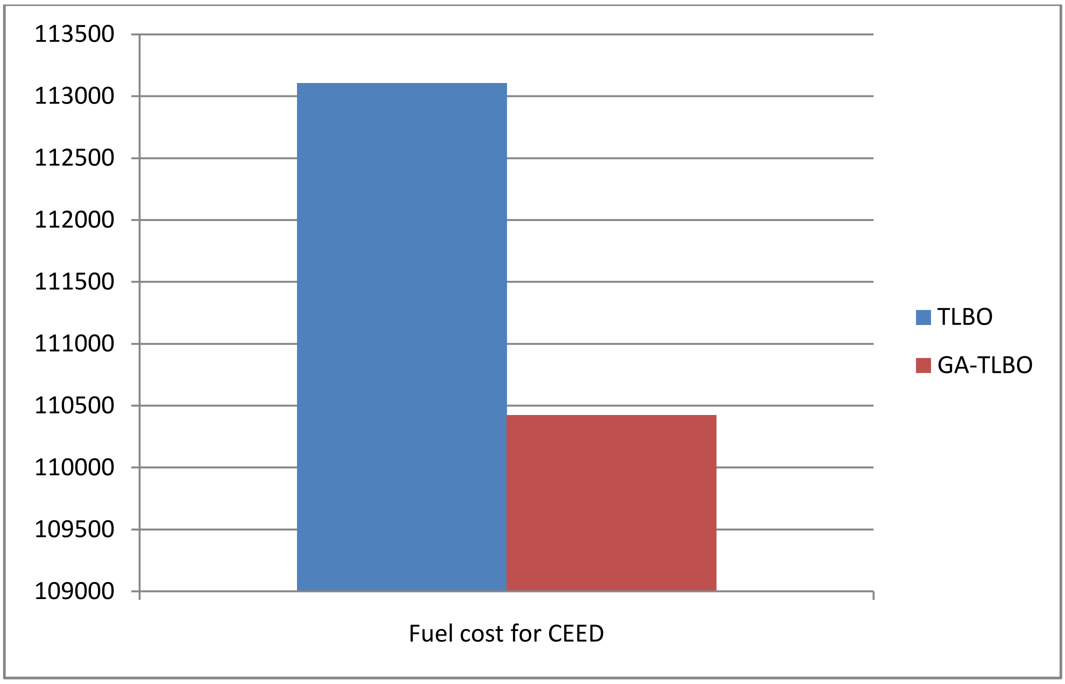


Fig 5.10 Comparison of fuel cost for CEED by TLBO, GA-TLBO

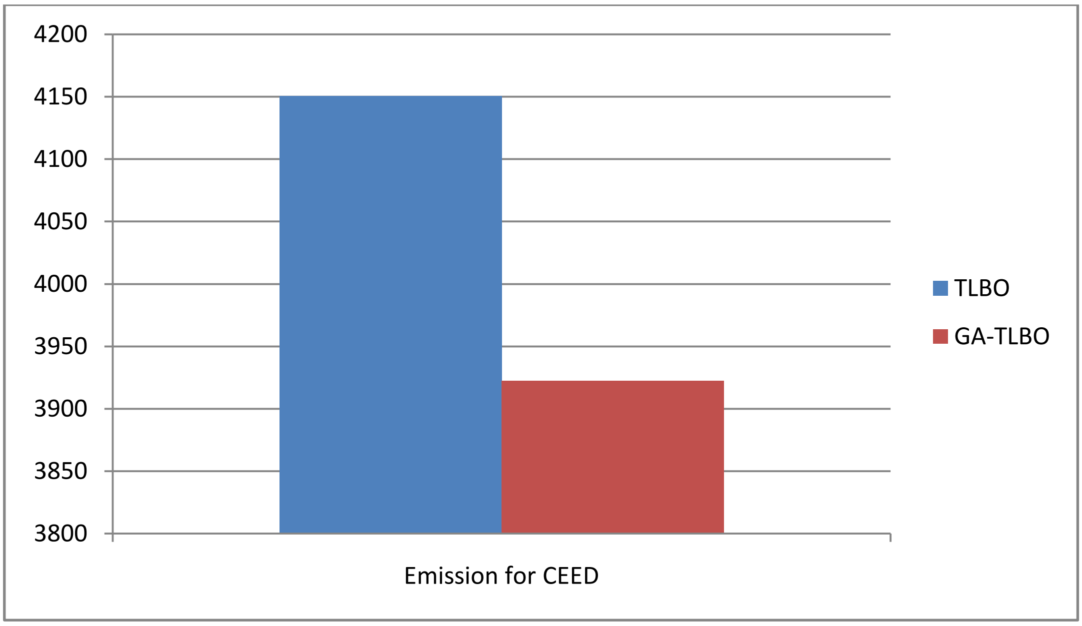


Fig 5.11 Comparison of emission for CEED by TLBO, GA-TLBO

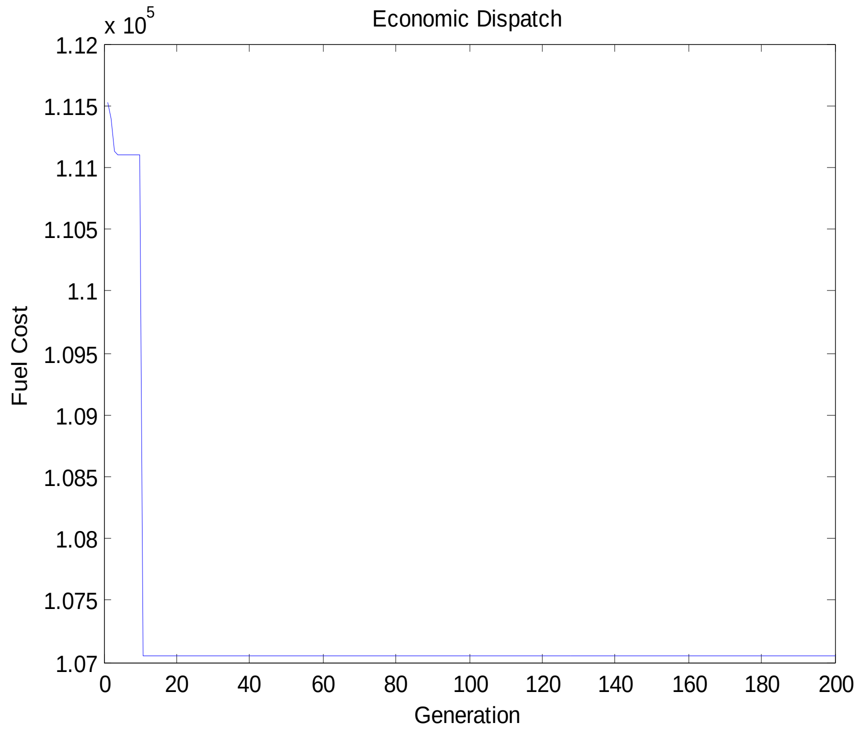


Fig 5.12Convergence criterion for ELD for 10units

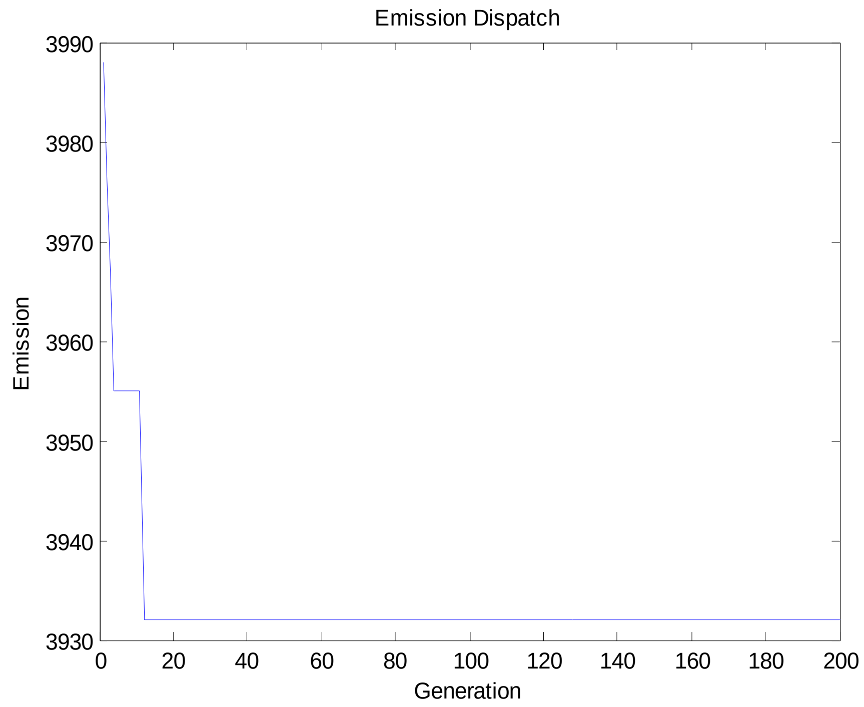


Fig 5.13Convergence criterion for EED for 10 units

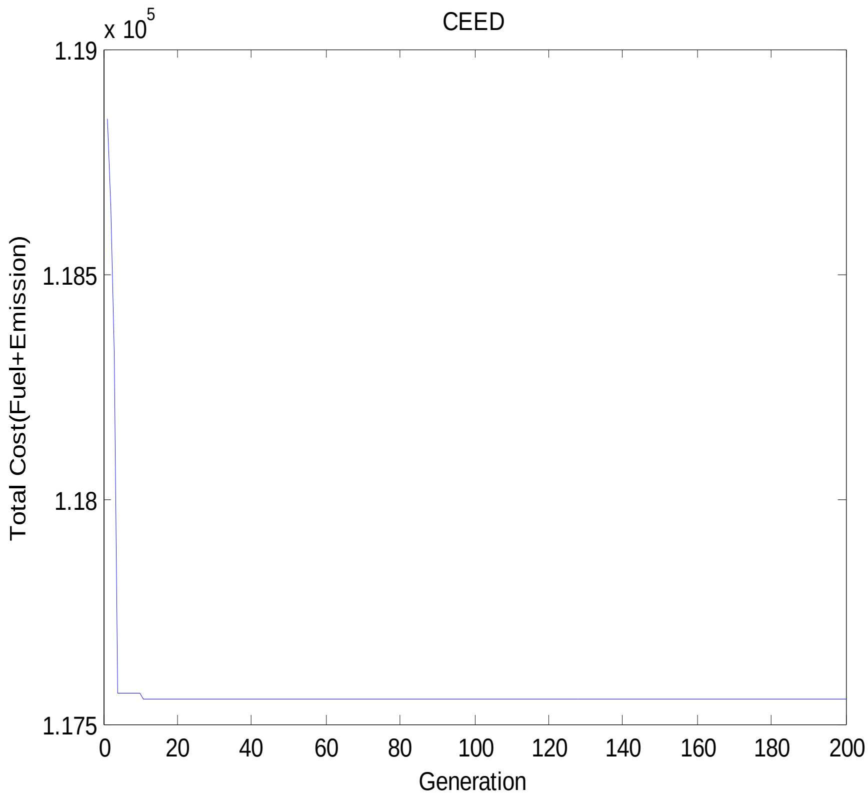


Fig 5.14Convergence criterion for CEED for 10 units

5.4.3 Test case 3

The results of solution ELD, EED and CEED by GA-TLBO for 13 unit system are given in Table 5.7, 5.8 and 5.9respectively. Results obtained by TLBO are also shown for comparison..Table 5.7, 5.8 and 5.9 shows that GA- TLBO has better convergence criterion. Fig.5.15, Fig.5.16, Fig.5.17 and Fig.5.18 signifies the graphical representation of the results reported in Table 5.7, 5.8 and 5.9.Fig.5.19, Fig.5.20 and Fig.5.21 show the convergence criterion for ELD, EED and CEED.

Table 5.7 Economic Load Dispatch by TLBO and GA-TLBO for 13 units

Generator	Economic load dispatch by TLBO	Economic load dispatch by GA-TLBO
PG1	628.32	628.32
PG2	222.75	222.75
PG3	149.6	149.6
PG4	109.87	109.87
PG5	60	60
PG6	109.87	109.87
PG7	109.87	109.87
PG8	109.87	109.87
PG9	109.87	109.87
PG10	40	40
PG11	40	40
PG12	55	55
PG13	55	55
FUEL COST	17963.83	17963.83
EMISSION	461.48	461.48
ITERATION	23	14

Table 5.8 Economic Emission Dispatch by TLBO and GA-TLBO for 13 units

Generator	Economic Emission dispatch by TLBO	Economic Emission dispatch by GA-TLBO
PG1	80.64	80.64
PG2	166.33	166.33
PG3	166.33	166.33
PG4	154.73	154.73
PG5	154.73	154.73
PG6	154.73	154.73
PG7	154.73	154.73
PG8	154.73	154.73
PG9	154.73	154.73
PG10	119.96	119.96
PG11	119.96	119.96
PG12	109.19	109.19
PG13	109.19	109.19
FUEL COST	19145.57	19145.57
EMISSION	58.24	58.24
ITERATION	22	14

Table 5.9 Combined Economic Emission Dispatch by TLBO and GA-TLBO for 13 units

Generator	CEED by TLBO	CEED by GA-TLBO
PG1	179.20	180
PG2	224.73	224.13
PG3	299.21	298.44
PG4	159.61	160
PG5	109.87	159.73
PG6	159.72	159.74
PG7	159.64	159.70
PG8	159.74	159.63
PG9	158.04	109.86
PG10	40.01	40
PG11	40	40
PG12	55	55
PG13	55.11	55
FUEL COST	18047.063	18041.84
EMISSION	85.8	85.695
ITERATION	22	14

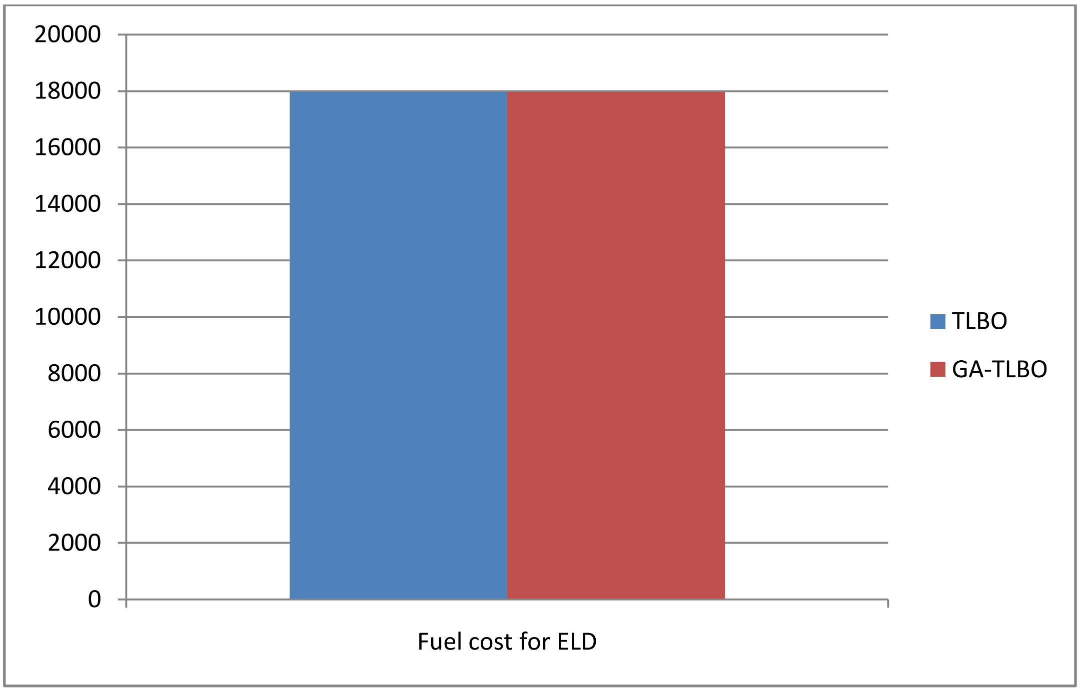


Fig 5.15 Comparison of fuel cost for ELD by TLBO, GA-TLBO

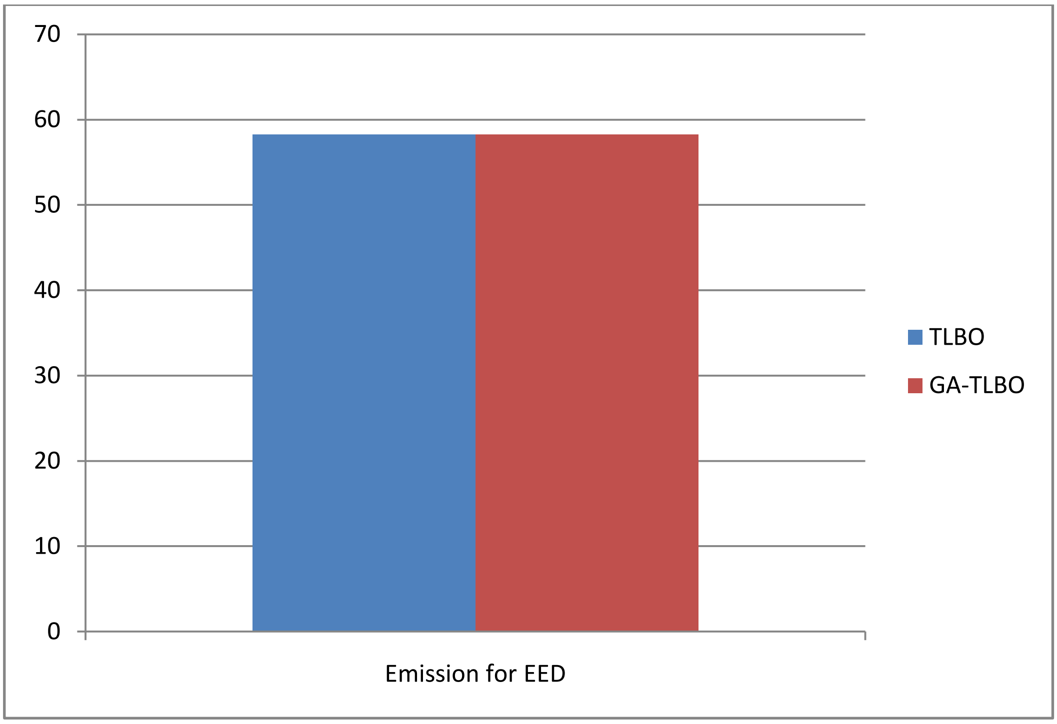


Fig 5.16 Comparison of emission for EED by TLBO, GA-TLBO

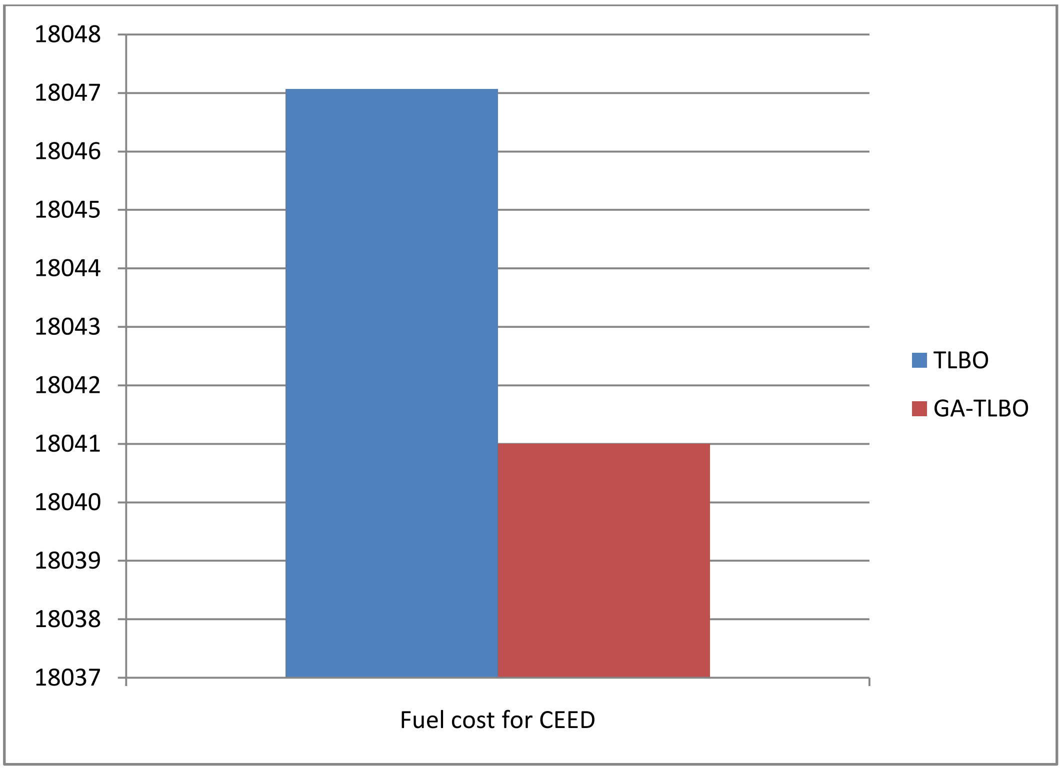


Fig 5.17 Comparison of fuel cost for CEED by TLBO, GA-TLBO

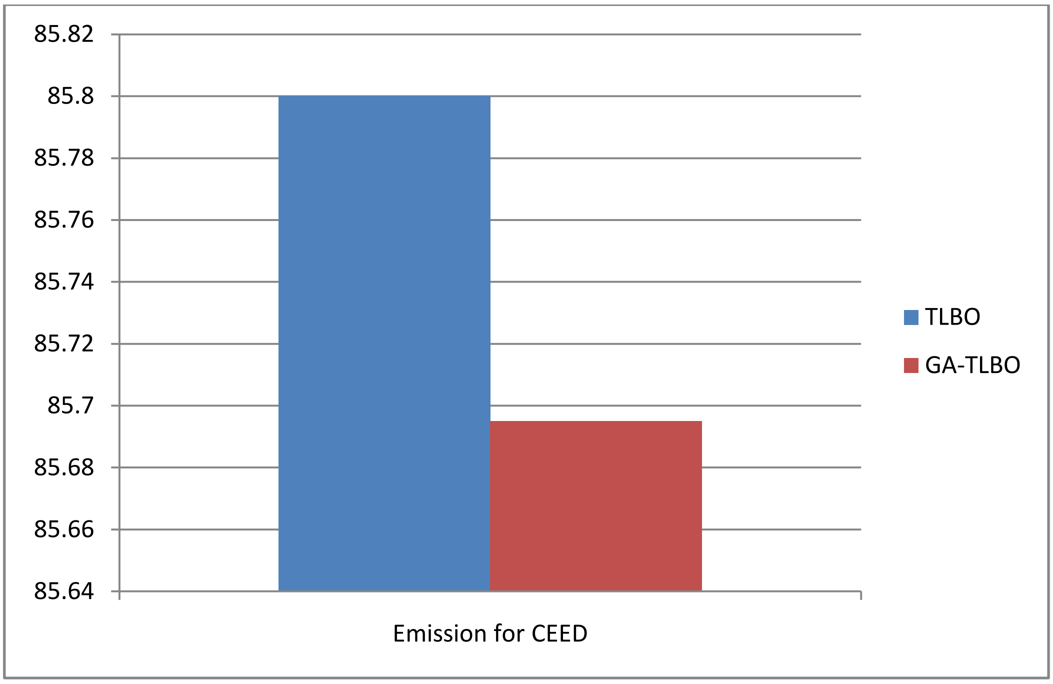


Fig 5.18 Comparison of emission for CEED by TLBO, GA-TLBO

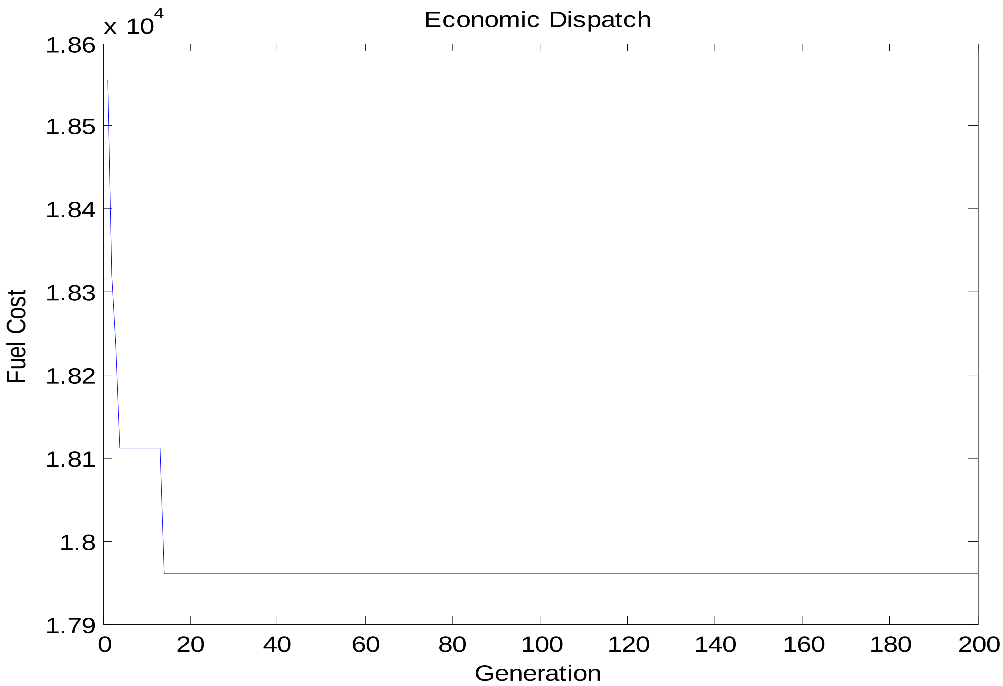


Fig 5.19Convergence criterion for ELD for 13 units

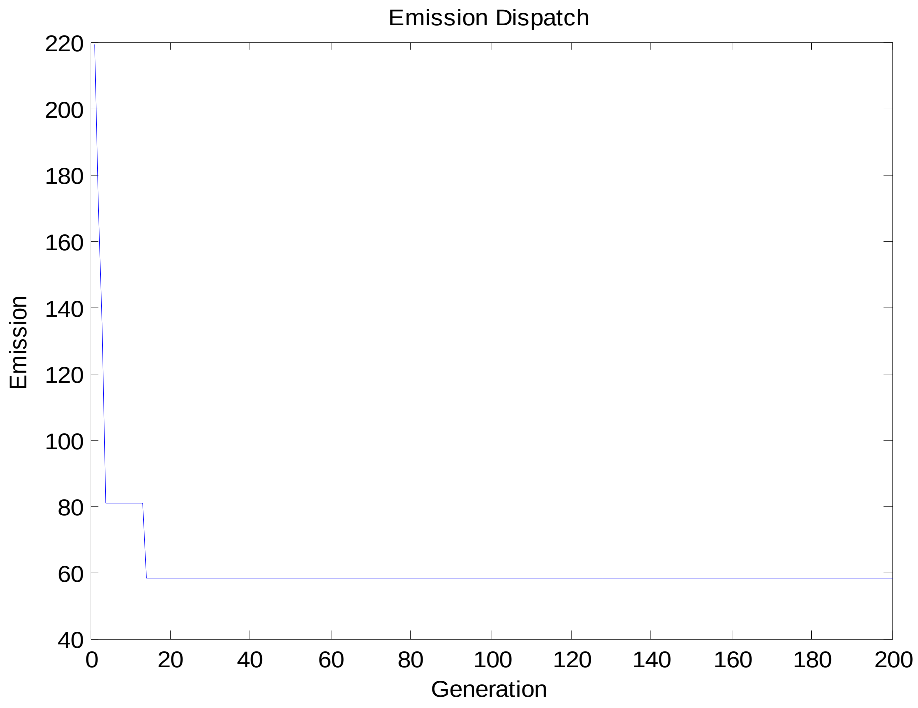


Fig 5.20Convergence criterion for EED for 13 units

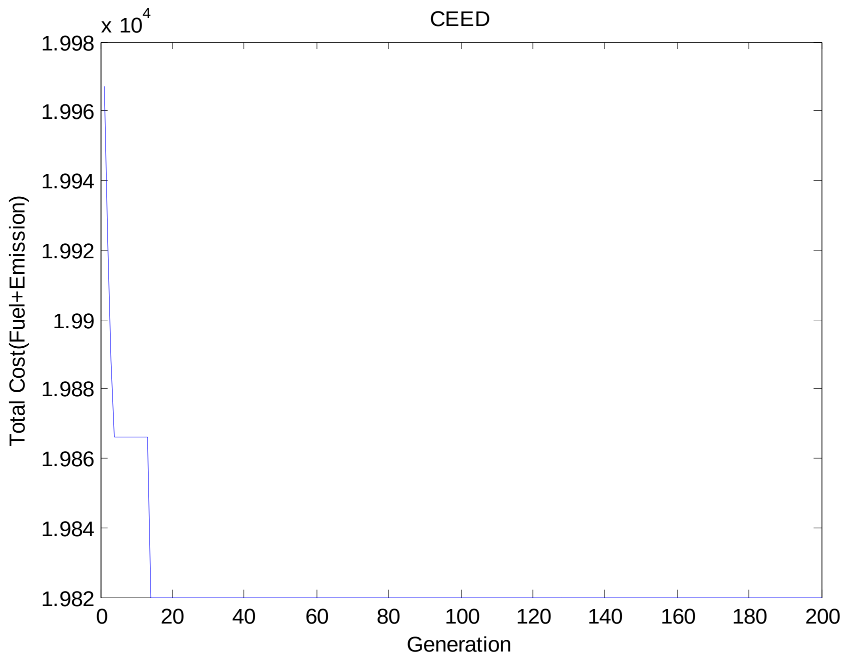


Fig 5.21Convergence criterion for C EED for 13 units

5.5 Conclusion

In this chapter the problem of ELD, EED as well as CEED are solved for three test cases. All the aforementioned problems are of prime importance for power system engineers as well as environmentalists of 21st century. Emission and load are two conflicting objective functions which need to be modeled from multi-objective approach. TLBO is combined with GA and applied to solve these problems. The fusion of GA and TLBO gives better results as well as better convergence criterion thereby establishing the benefit of hybridization.

CHAPTER 6

Solution of combined economic emission dispatch by hybrid TLBO-SQP

6.1 Introduction

Combined Economic Emission Dispatch of load is the most recent optimization problem of power system which can be solved by classical as well as modern optimization techniques. Classical techniques are keen to converge to a local optima and incapable of handling large number of inequality constrains. Modern evolutionary optimization technique like PSO, GA, EP, ABC. TLBO etc are also applied to solve CEED problem. It has been shown in chapter 4 that among them TLBO gives better results in terms of computational time. But these methods have the problem of premature convergence in their performance. In this context, Various hybrid methods have been applied to solve CEED. These hybrid optimization methods were found to be more effective and accurate, In this chapter a hybrid technique of optimization involving TLBO and SQP is developed. SQP is one of best nonlinear-programming method for constrained optimization.

6.2 Overview of sequential quadratic programming

Out of a number of nonlinear programming method of optimization, SQP Method is very much handy for constrained optimization problem. SQP iteratively approximate the Nonlinear Programming problem by a sequence of Quadratic

Programming sub problem.[5] . The quadratic sub problem is formulated to have result of sequence of solutions converge to a local optimum of NLP. It is one of the best in terms of efficiency, accuracy and percentage of successful solution over a large number of test problems. IT is similar to Newton's method for constrained optimization. Broyden –Fletcher-Goldfarb-Shanno quasi-Newton updating method is utilized to make an approximation of Hessian of the Lagrangian function. Quadratic programming sub problem is formulated by using the result of the above approximation. The solution of the sub problem create a search direction for a line search procedure. CEED is a non convex and no smooth function, SQP gives a local minima initially. In this paper TLBO is used as a global search and the best solution of TLBO is taken as initial condition for SQP method for fine tune solution which is a local minima.

Consider the application of the SQP methodology to nonlinear optimization problems,

Min. f(x)

Subject to

h(x)=0

$g(x)\leq 0$

The Lagrangian of this problem can be written as,

$L(x,\lambda.\mu)=f(x)+ \lambda h(x)+ \mu^T g(x)$

where λ and μ are vectors of multipliers. SQP is an iterative procedure which models the problem for a given iterate x_k by a quadratic programming sub-problem, solves that quadratic programming sub-problem, and then uses the solution to construct a new iterate x_{k+1}

The sub problem can be constructed by linearizing the constraints around x_k as follows

Where H is the Hessian matrix.

Subject to

$$h(x^k) + \nabla h(x^k)(x - x^k) = 0$$
$$g(x^k) + \nabla g(x^k)(x - x^k) \le 0$$

We need to update the multipliers in a corresponding search direction and choose a step size to evaluate the next iterate.

6.3 TLBO-SQP applied to CEED

The hybrid TLBO-SQP algorithm is applied to solve combined economic emission dispatch for optimal fuel cost and emission. The TLBO is used to find a near global solution and SQP is used as a local search to determine the optimal solution at the final.

The sequential steps involved in solution of CEED by TLBO-SQP are as explained below

Step 1: Input the total number of learners, number of subjects offered to the learners, cost coefficients, loss coefficients, load demand and limits of the constraints. Here the number of learners in a class is considered as population and the number of subjects offered to the learner is considered as generators..

Step 2: Generate the initial population which satisfies the limits and constraints.

Step 3: Objective function of each individual is calculated.

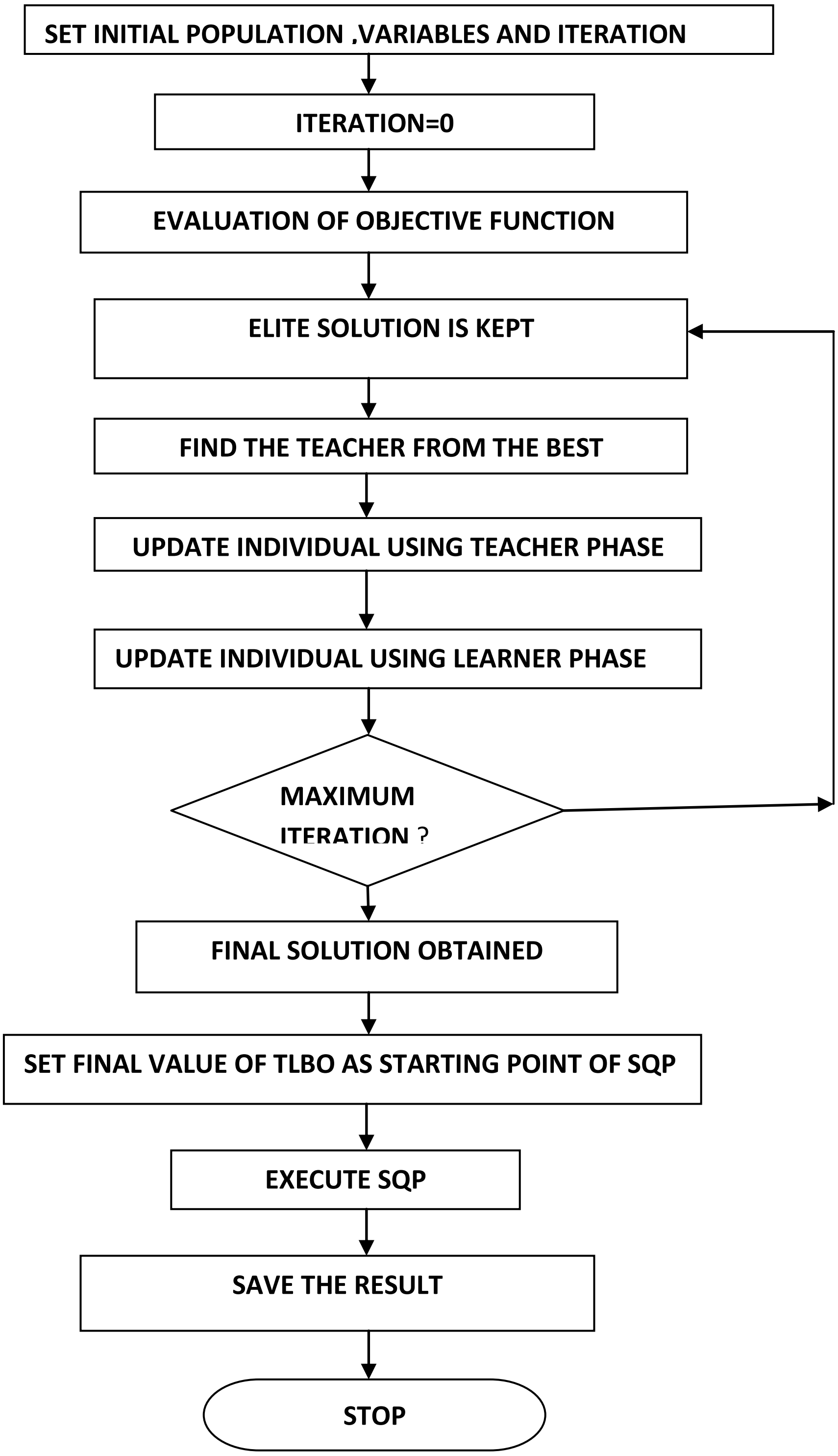
Step 4: In the current iteration the best solution is considered as the teacher and the new value of population is generated in the teacher phase. If any new individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 5: New learners are evaluated in learner phase. If any new individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 6: Check for termination criteria. If the termination criterion is met go to step 7 otherwise repeat from step 4.

Step 7: Apply the solution obtained from step 6 of TLBO as initial point of SQP and solve the SQP. Here the SQP method will be used to fine-tune the improving (better fitness) solution

6.4 Flowchart of TLBO-SQP applied to CEED



6.5 Results and Discussion

The proposed SQP TLBO algorithm is applied to solve ELD, EED and CEED for three different test cases**.**

Test case 1: 6 unit system

Test case 2: 10 unit System

Test case 3: 13 unit System

6.5.1 Test case 1

The results of solution ELD, EED and CEED by SQP-TLBO for 6 unit system are given in Table 6.1, 6.2 and 6.3 respectively. Results obtained by TLBO and GA-TLBO are also shown for comparison. Table 6.1 depicts that the fuel cost in case of ELD for 6 unit system obtained by TLBO, GA-TLBO and SQP-TLBO are 602.406$,602,404$ and 602.402$ respectively which clearly reveals the fact that fusion of SQP with TLBO gives better performance. Similar kind of result is observed for EED and CEED as well. Better performance is obtained in terms of convergence criterion and also as the number of iterations is less for SQP- TLBO. Fig.6.1, Fig6..2, Fig.6.3 and Fig6..4 signifies the graphical representation of the results reported in table 6.1, table 6.2 and table 6.3.

Table 6.1 Economic Load Dispatch by TLBO and GA-TLBO and TLBO-SQP for 6 units

Generator	Economic load dispatch by TLBO	Economic load dispatch by GA-TLBO	Economic load dispatch by TLBO-SQP
PG1	0.129	0.127	0.127
PG2	0.298	0.299	0.298
PG3	0.455	0.453	0.454
PG4	1.122	1.1175	1.1175
PG5	0.52	0.5290	0.5290
PG6	0.314	0.3146	0.3146
FUEL COST	602.406	602.404	602.402
EMISSION	0.2302	0.2299	0.2299

Table 6.2 Economic Emission Dispatch by TLBO and GA-TLBO and TLBO-SQP for 6 units

Generator	Economic Emission dispatch by TLBO	Economic Emission dispatch by GA-TLBO	Economic Emission dispatch by TLBO-SQP
PG1	0.411	0.4099	0.4099
PG2	0.477	0.4721	0.4721
PG3	0.548	0.5456	0.5456
PG4	0.384	0.3955	0.3955
PG5	0.548	0.5387	0.5387
PG6	0.518	0.5239	0.5239
FUEL COST	651.14	650.05	650.05
EMISSION	0.194	0.1942	0.1942

Table 6.3 Combined Economic Emission Dispatch by TLBO and GA-TLBO and TLBO-SQP for 6 units

Generator	CEED by TLBO	CEED by GA-TLBO	CEED by TLBO-SQP
PG1	0.259	0.255	0.256
PG2	0.281	0.361	0.361
PG3	0.632	0.636	0.637
PG4	0.724	0.743	0.743
PG5	0.592	0.479	0.479
PG6	0.381	0.39	0.3899
FUEL COST	616.001	615.01	614.97
EMISSION	0.2044	0.204	0.2036

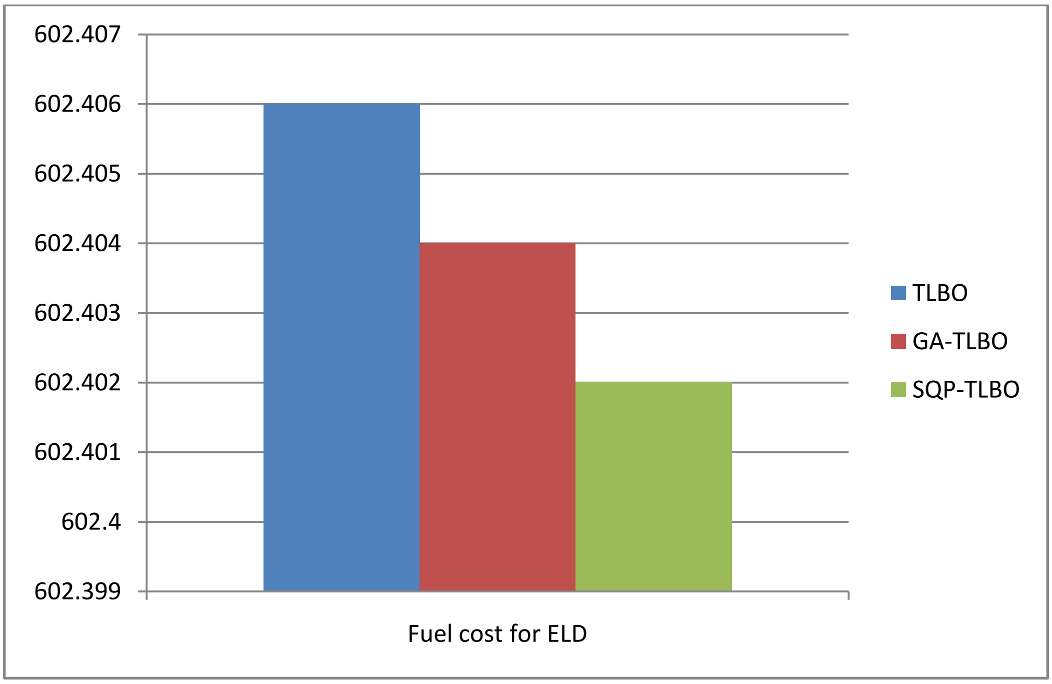


Fig 6.1 Comparison of fuel cost for ELD by TLBO, GA-TLBO and TLBO-SQP

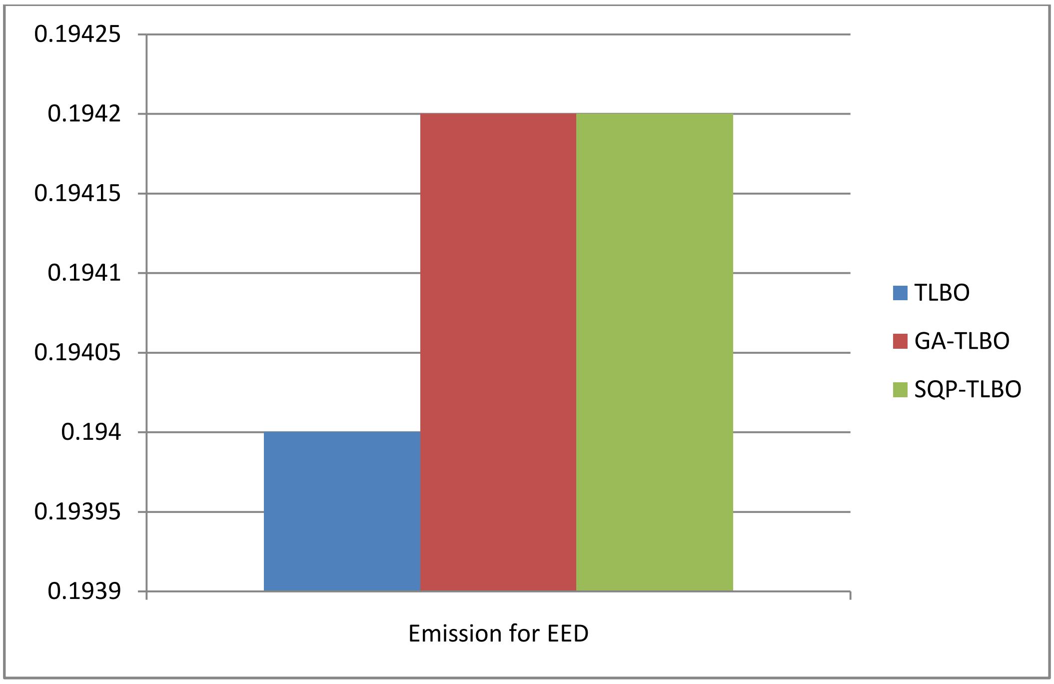


Fig 6.2 Comparison of emission for EED by TLBO, GA-TLBO and –TLBO-SQP

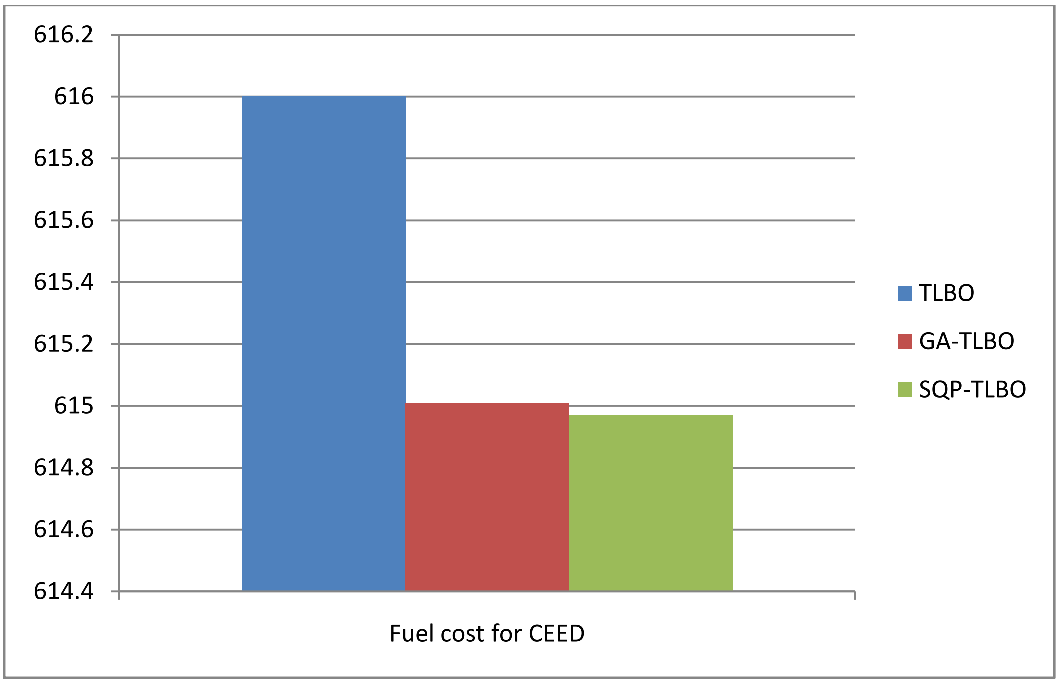


Fig 6.3 Comparison of fuel cost for CEED by TLBO, GA-TLBO and TLBO-SQP

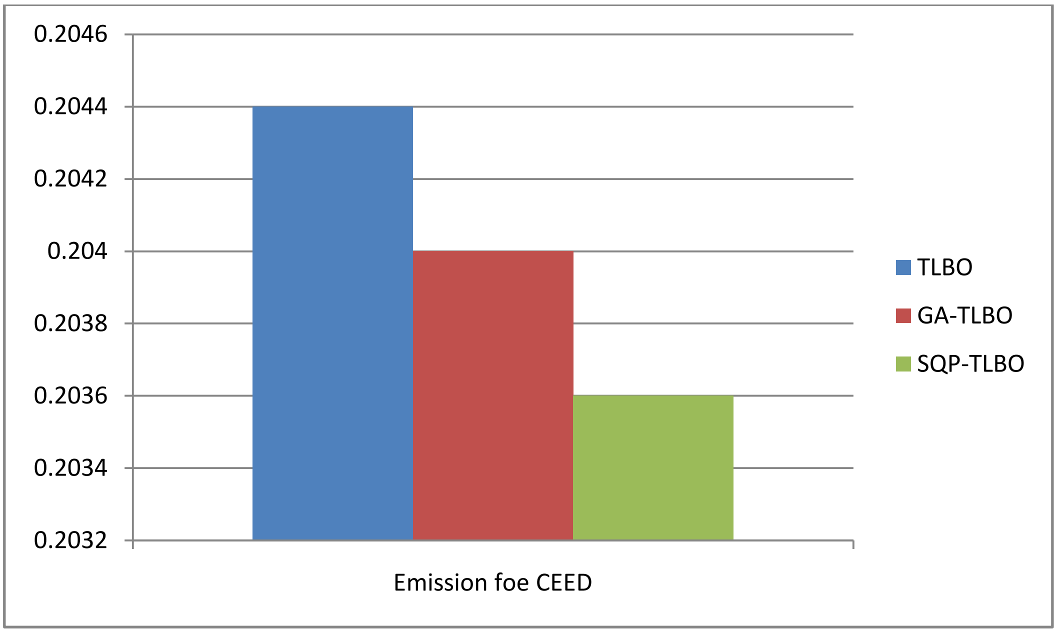


Fig 6.4 Comparison of emission for CEED by TLBO, GA-TLBO and TLBO-SQP

6.5.2 Test case 2

The results of solution ELD, EED and CEED by SQP-TLBO for 10 unit system are shown in Table 6.4, 6.5 and 6,6 respectively. Results obtained by TLBO and GA-TLBO are also given for comparison.

Table 6.4 depicts that the fuel cost in case of ELD for 10 unit system obtained by TLBO , GA-TLBO and SQP-TLBO are111497.632 $, 108015.0$ and107049.0 $ respectively which clearly reveals the fact that fusion of SQP with TLBO gives better performance. Similar kind of result is observed for EED and CEED as well. Better performance is obtained in terms of convergence criterion and also as the number of iterations is less for SQP- TLBO. Fig.6.5, Fig6..6, Fig.6.7 and Fig6..8 signifies the graphical representation of the results reported in table 6.4, table 6.5 and table 6.6

Table 6.4 Economic Load Dispatch by TLBO and GA-TLBO and TLBO-SQP for 10 units

Generator	**Economic load dispatch by TLBO**	**Economic load dispatch by GA-TLBO**	**Economic load dispatch by TLBO-SQP**
PG1	55	40.5326	40.5326
PG2	79.999	45.8383	45.8383
PG3	106.946	115.7578	115.7578
PG4	100.607	104.3776	104.3776
PG5	81.478	104.7259	104.7259
PG6	83.007	112.6931	112.6931
PG7	299.999	285	284.9527
PG8	339.999	252.21	251.1221
PG9	469.999	470.00	470.00
PG10	469.999	470.00	470.00
FUEL COST	111497.632	108015.0	107049.0
EMISSION	4572.362	4123.7	4118.29

Table 6.5 Economic Emission Dispatch by TLBO and GA-TLBO and TLBO-SQP for 10 units

Generator	Economic Emission dispatch by TLBO	Economic Emission dispatch by GA-TLBO	Economic Emission dispatch by TLBO-SQP
PG1	55	55	55
PG2	80	80	80
PG3	81.134	82.13	81.13
PG4	81.363	81.36	81.36
PG5	160	81.5	81.5
PG6	240	160	160
PG7	294.485	240	240
PG8	297.27	295.48	294.48
PG9	396.77	396.76	396.76
PG10	395.576	395.57	395.57
FUEL COST	116412.443	116512.44	116412.44
EMISSION	3932.243	3932.24	3932.24

Table 6.6 Combined Economic Emission Dispatch by TLBO and GA-TLBO and TLBO-SQP for 10 units

Generator	CEED by TLBO	CEED by GA-TLBO	CEED by TLBO-SQP
PG1	54.888	46.49749	46.49749
PG2	79.96	75	73.58246
PG3	86.586	75.37136	75.37136
PG4	83.74	63.07534	63.07534
PG5	134.27	99.64559	99.64559
PG6	157.134	240.0000	240.0000
PG7	297.64	227	226.8554
PG8	217.295	340.0090	340.0090
PG9	440.48	470.0000	470.0000
PG10	432.23	364.9724	364.9724
FUEL COST	113106.894	110421.605	110337.605
EMISSION	4150.496	3922.49	3908.49

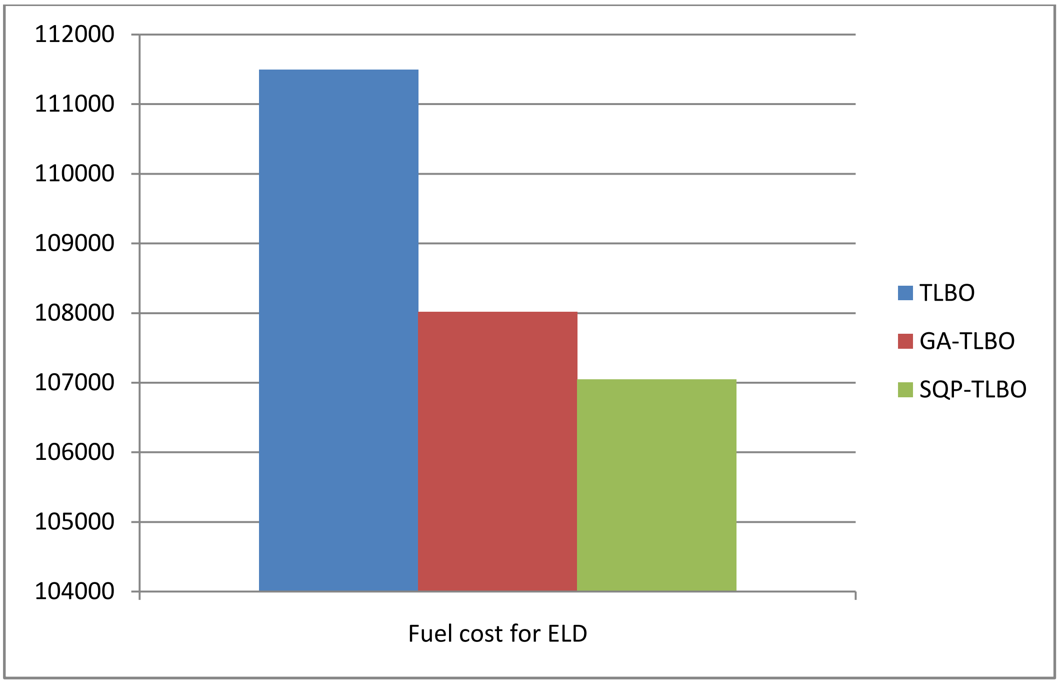


Fig 6.5 Comparison of fuel cost for ELD by TLBO, GA-TLBO and-TLBO-SQP

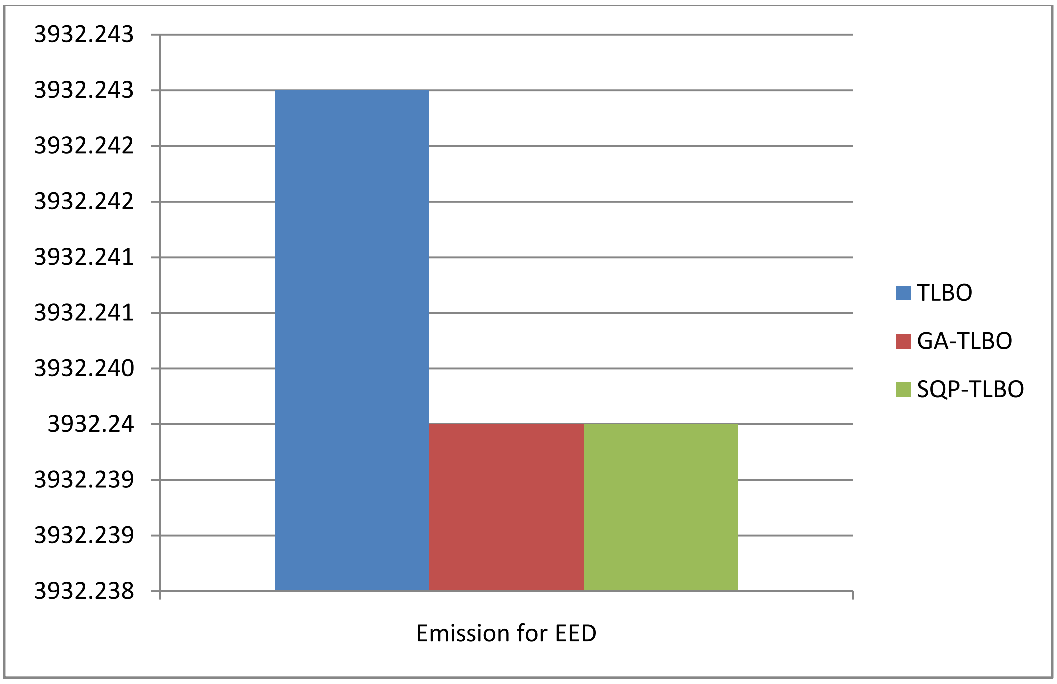


Fig 6.6 Comparison of Emission for EED by TLBO, GA-TLBO and TLBO-SQP

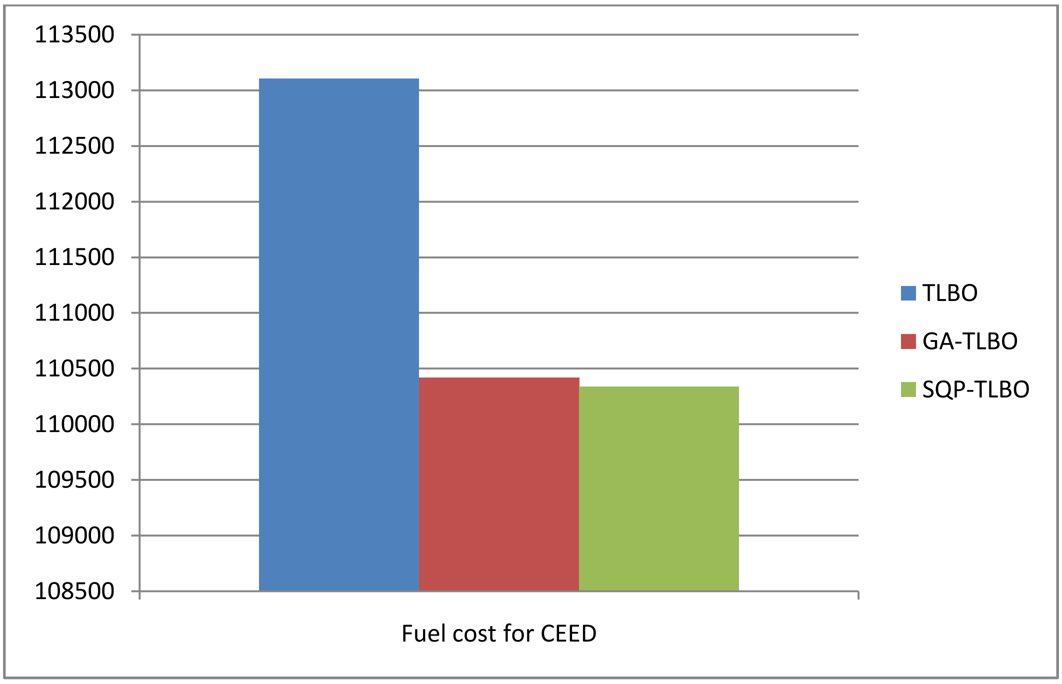


Fig 6.7 Comparison of fuel cost for CEED by TLBO, GA-TLBO and TLBO-SQP

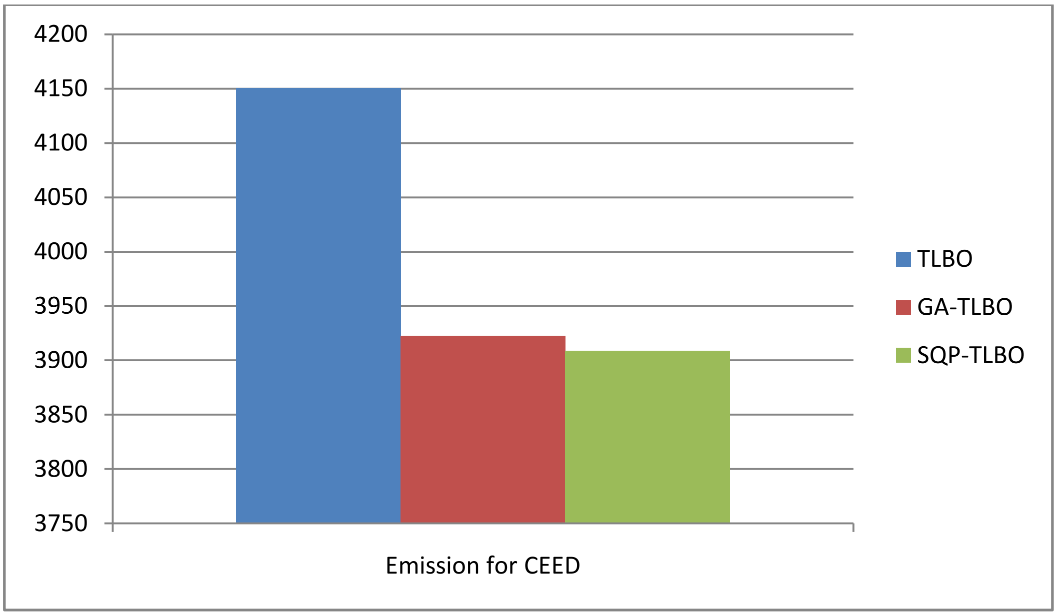


Fig 6.8 Comparison of emission for CEED by TLBO, GA-TLBO and TLBO-SQP

6.5.3 Test case 3

The results of solution ELD, EED and CEED by SQP-TLBO for 13 unit system are shown in Table 6.7, 6.8 and 6.9 respectively. Results obtained by TLBO and GA-TLBO are also given for comparison.

Table 6.7 depicts that the fuel cost in case of ELD for 13 unit system obtained by TLBO , GA-TLBO and SQP-TLBO are17963.83 $,17963.83 $ and17963.83 $ respectively which clearly reveals the fact that fusion of SQP with TLBO gives better performance. Similar kind of result is observed for EED and CEED as well. Better performance is obtained in terms of convergence criterion and also as the number of iterations is less for SQP- TLBO. Fig.6.9, Fig6..10, Fig.6.11 and Fig6..12signifies the graphical representation of the results reported in table 6.7, table 6.8 and table 6.9

Table 6.7 Economic Load Dispatch by TLBO and GA-TLBO and TLBO-SQP for 13 units

Generator	Economic load dispatch by TLBO	Economic load dispatch by GA-TLBO	Economic load dispatch by TLBO-SQP
PG1	628.32	628.32	628.32
PG2	222.75	222.75	222.75
PG3	149.6	149.6	149.6
PG4	109.87	109.87	109.87
PG5	60	60	60
PG6	109.87	109.87	109.87
PG7	109.87	109.87	109.87
PG8	109.87	109.87	109.87
PG9	109.87	109.87	109.87
PG10	40	40	40
PG11	40	40	40
PG12	55	55	55
PG13	55	55	55
FUEL COST	17963.83	17963.83	17963.83
EMISSION	461.48	461.48	461.48

Table 6.8 Economic Emission Dispatch by TLBO and GA-TLBO and SQP-TLBO for 13 units

Generator	Economic Emission dispatch by TLBO	Economic Emission dispatch by GA-TLBO	Economic Emission dispatch by TLBO-SQP
PG1	80.64	80.64	80.64
PG2	166.33	166.33	166.33
PG3	166.33	166.33	166.33
PG4	154.73	154.73	154.73
PG5	154.73	154.73	154.73
PG6	154.73	154.73	154.73
PG7	154.73	154.73	154.73
PG8	154.73	154.73	154.73
PG9	154.73	154.73	154.73
PG10	119.96	119.96	119.96
PG11	119.96	119.96	119.96
PG12	109.19	109.19	109.19
PG13	109.19	109.19	109.19
FUEL COST	19145.57	19145.57	19145.57
EMISSION	58.24	58.24	58.24

Table 6.9 Combined Economic Emission Dispatch by TLBO and GA-TLBO and TLBO-SQP for 13 units

Generator	CEED by TLBO	CEED by GA-TLBO	CEED by-TLBO-SQP
PG1	179.20	180	179.025
PG2	224.73	224.13	224.13
PG3	299.21	298.44	298.44
PG4	159.61	160	159.73
PG5	109.87	159.73	159.73
PG6	159.72	159.74	159.74
PG7	159.64	159.70	159.70
PG8	159.74	159.63	159.63
PG9	158.04	109.86	109.86
PG10	40.01	40	40
PG11	40	40	40
PG12	55	55	55
PG13	55.11	55	55
FUEL COST	18047.063	18041.84	18038.84
EMISSION	85.8	85.695	85.65

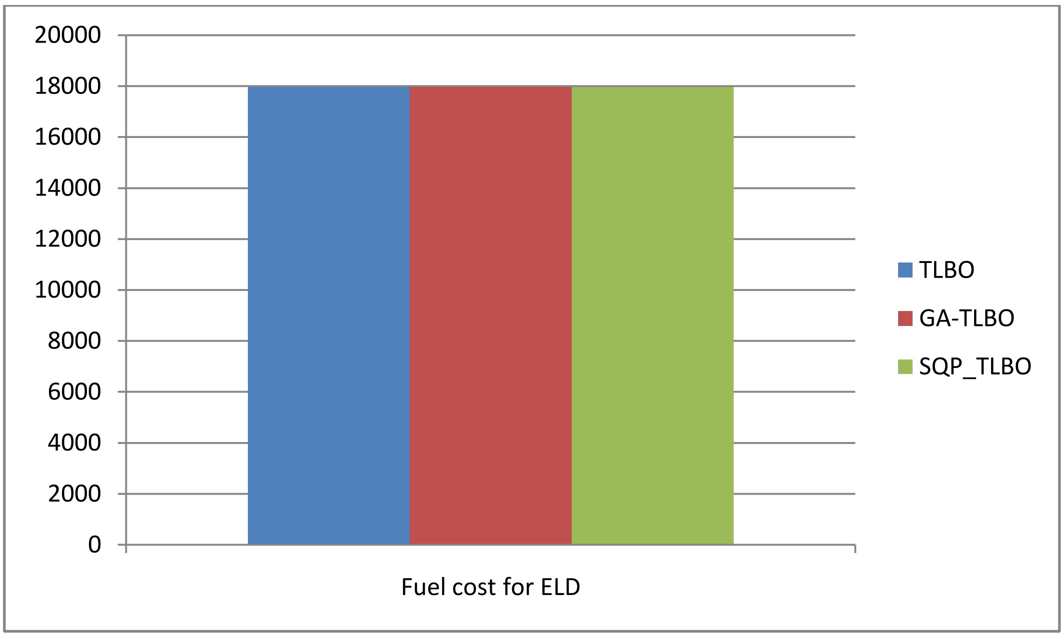


Fig6. 9 Comparison of fuel cost for ELD by TLBO, GA-TLBO and TLBO-SQP

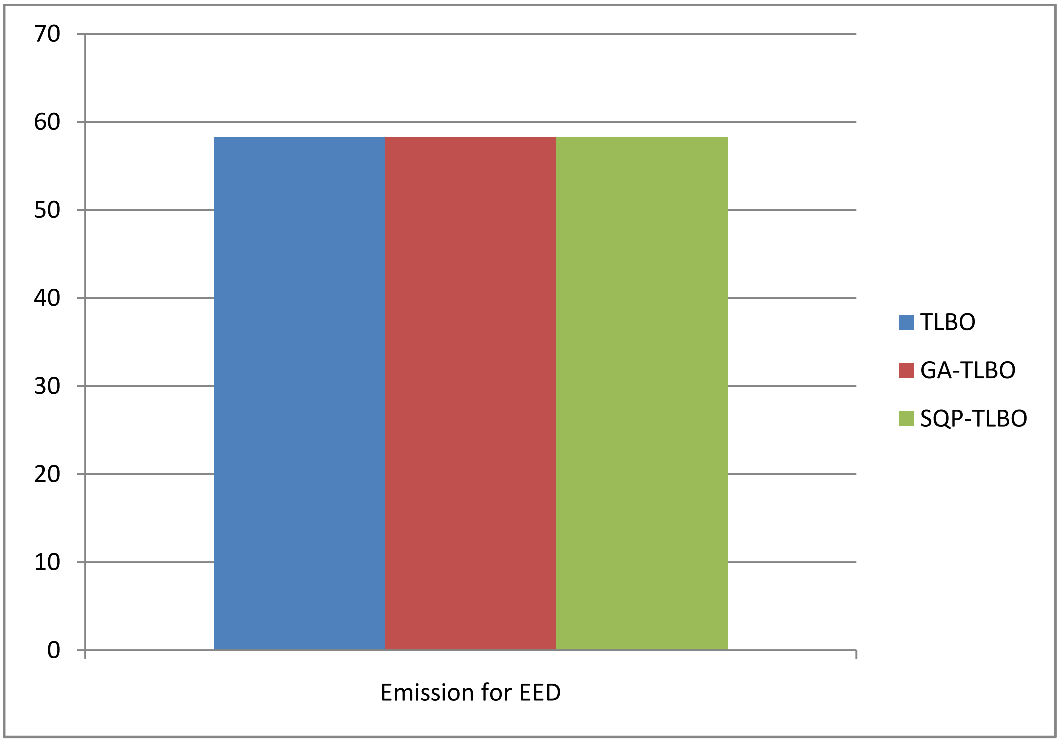


Fig 6.10 Comparison of emission for EED by TLBO, GA-TLBO and TLBO-SQP

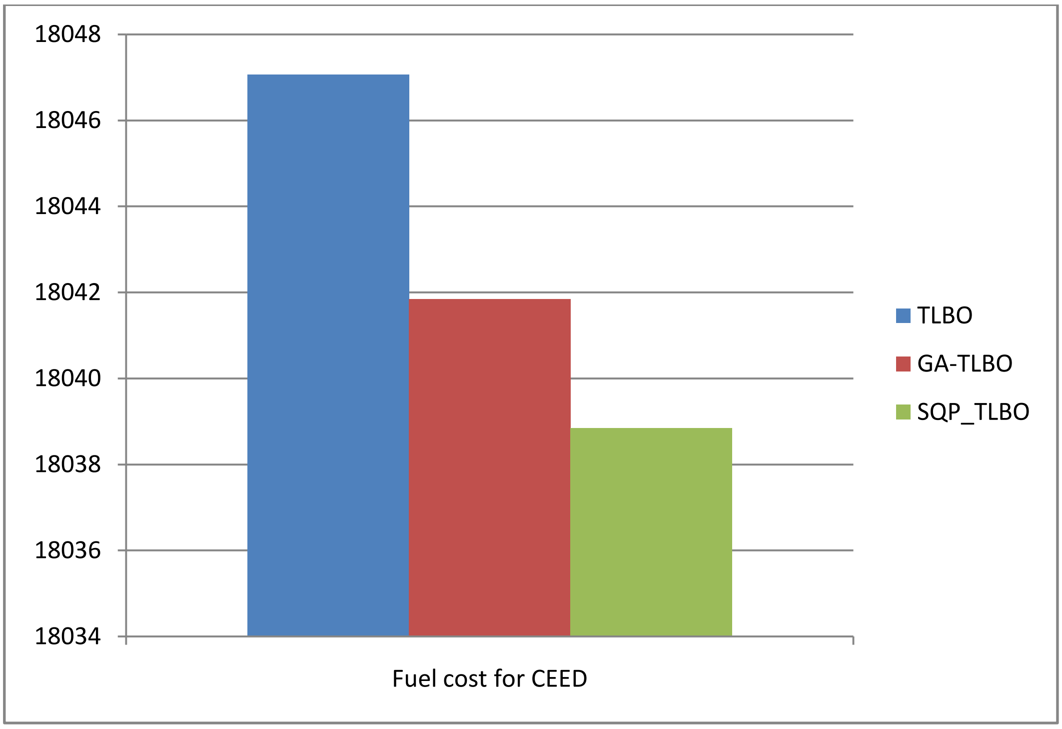


Fig 6.11 Comparison of fuel cost for CEED by TLBO, GA-TLBO and TLBO-SQP

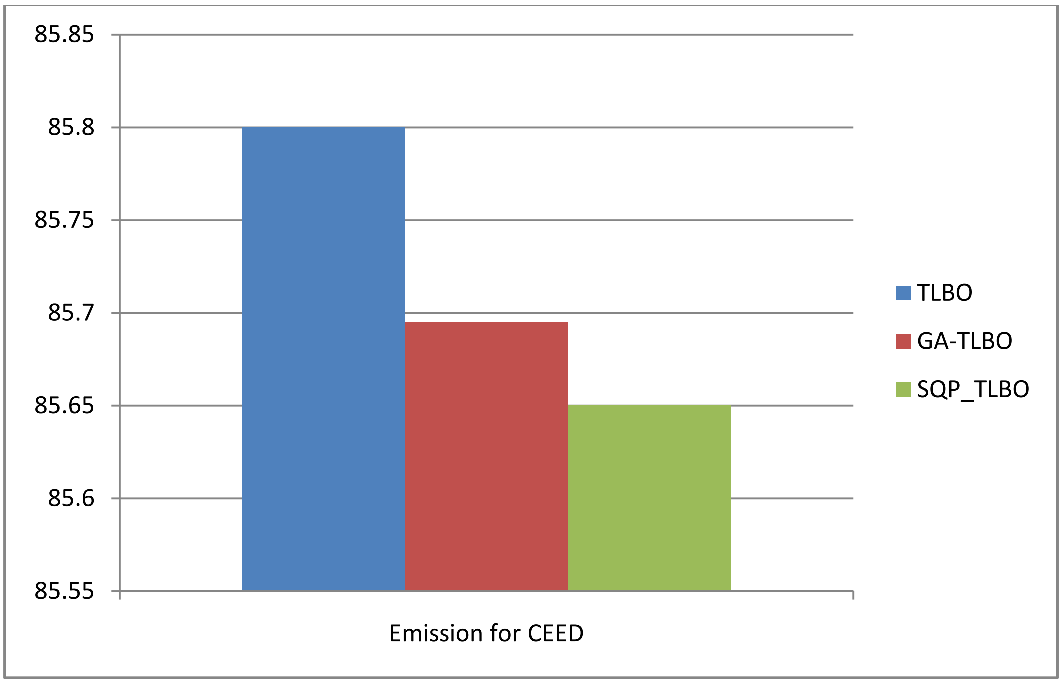


Fig 6.12 Comparison of emission for CEED by TLBO, GA-TLBO and TLBO-SQP

6.6 Conclusion

In this chapter the problem of ELD, EED as well as CEED problems are tried to solve for three test cases. All the aforesaid problems are of critical importance for power system engineers as well as environmentalists of present time. Emission and load are two opposite directional objective functions which need to be modeled from multi-objective approach. TLBO is combined with SQP to solve these problems. The fusion of SQP and TLBO gives no significant result for ELD and EED but slightly better results in case of CEED yielding the view that GA-TLBO is still more handy in the business.

CHAPTER7

7.1 Conclusion:

The economic load dispatch optimization problem mostly deals with the meticulous planning of load allocation to the individual generator of the group of generators being connected in parallel, within the condition of fulfilling the load demand without violating maximum and minimum output constraints, to minimize the operating cost. In earlier days operating cost function was considered as a simple quadratic function, the optimization problem being a static problem, start up fuel cost being insignificant and emission of fossil fuel being unimportant, the optimization problem were solved by many classical optimization techniques But now as the demand of electrical energy in the world increases day by day and most large electric power plants today depend on fossil fuels emission rate of pollutant increases also. So the effect of toxic emissions of fossil are to be incorporated to the cost function by penalty factor. In the above scenario, the operating cost function remains no longer as a simple quadratic function. The optimization of such nonlinear, non convex operating cost function representing combinatorial multi objectives becomes easier to solve by evolutionary optimization techniques

In this thesis, two evolutionary algorithms: GA and TLBO are applied separately to solve combined economic emission dispatch problem. Since TLBO has no tuning parameter, it has been shown in chapter 4 that TLBO gives better results than GA.

Since most of the evolutionary algorithms have the drawback of premature convergence or getting stuck at local optima, hybridization of two algorithms are done to solve CEED. Two hybrid algorithms are applied here; one combines two evolutionary algorithms GA and TLBO and another combines one evolutionary algorithm TLBO and one conventional algorithm SQP. Chapter 5 shows that the results of the application of the hybrid optimization GATLBO technique comes out to be better than both the GA and TLBO Technique in terms of less number iteration for convergence as well as fuel cost and emission. The comparison of convergence characteristic of GA, TLBO and GATLBO are shown in fig1 to fig 3.

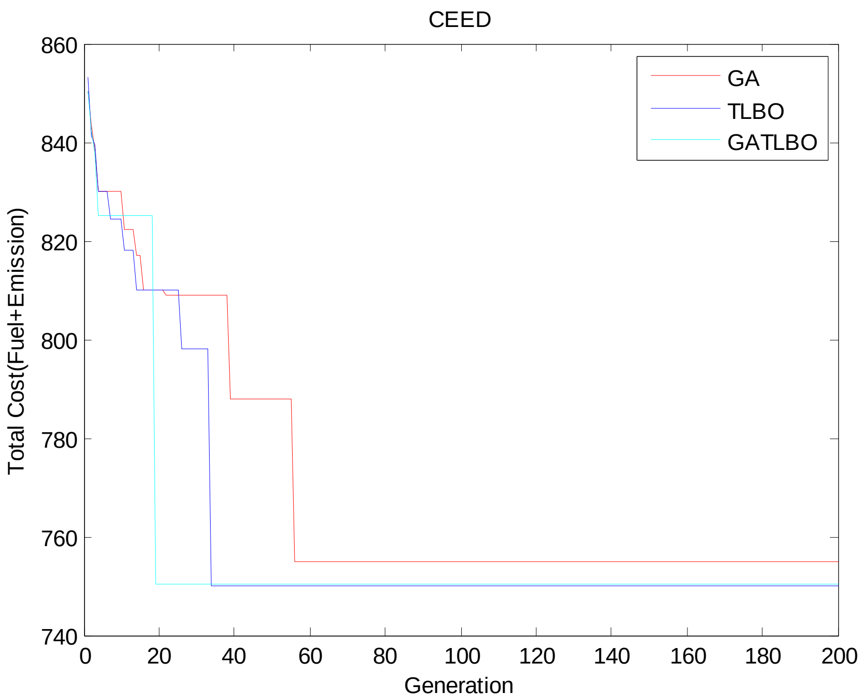


Fig 7.1Convergence characteristic of 6 unit system for CEED

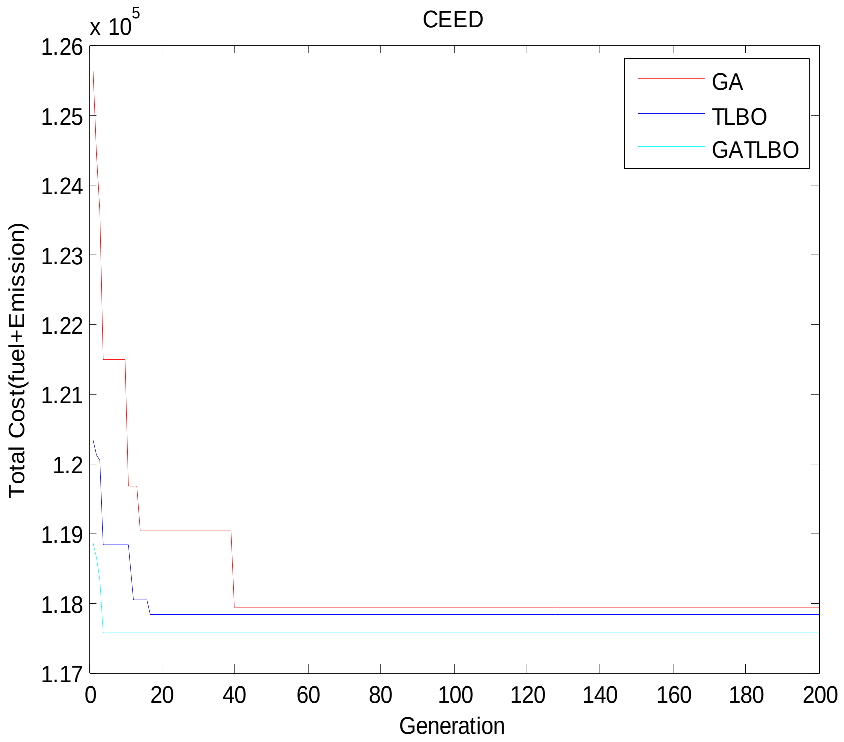


Fig 7.2 Convergence characteristic of 10 unit system for CEED

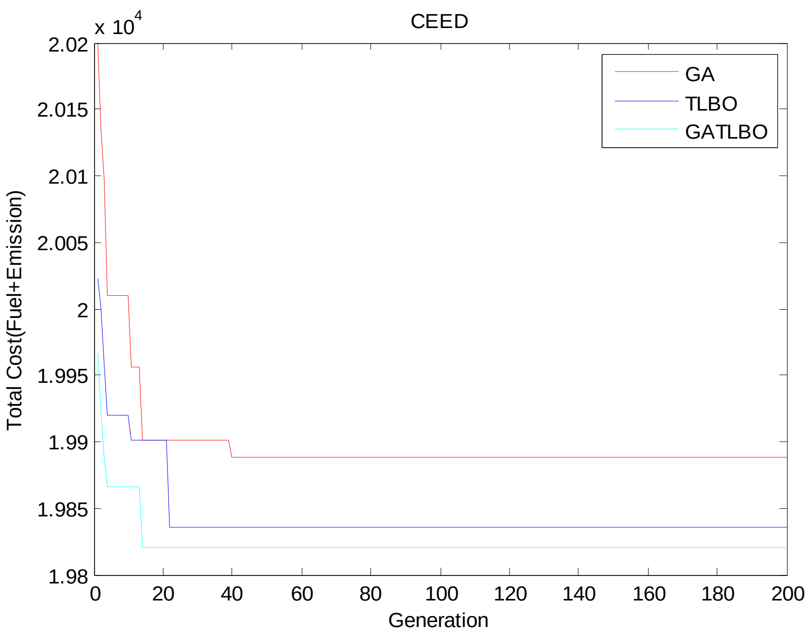


Fig7.3Convergence characteristic of 13 unit system for CEED

Figures show that GATLBO has better convergence than both GA and TLBO and hence less computation time is required for GATLBO.

In hybridization of two evolutionary techniques the problem of premature convergence or local optima may be still present. So a hybridization of one classical method and one evolutionary method is tried in chapter 6. The evolutionary method TLBO is applied initially and after convergence of TLBO, SQP is applied for fine tuning of the solution. It has been shown in chapter 6 that the fusion of SQP and TLBO gives better result for CEED.

7.2 Scope for future work

The present work has demonstrated that TLBO, GA-TLBO and TLBO-SQP are very efficient and reliable to find optimal solution to ELD, EED and CEED problem. There are some scopes of further work as mentioned below:

1. TLBO- GATLBO and TLBO-SQP may be employed to the combination of unit commitment and CEED problem where more constraints may be added in search for better and practical quality of results.
2. TLBO GATLBO and TLBOSQP may also be tried for hydrothermal scheduling and optimal power flow problem.

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ANNEXURE 1

TABLE AX 1

FUEL COST COEFFICIENT, EMISSION COST COEFFICIENT AND GENERATION OPERATION LIMIT FOR TEST CASE 1

UNIT	FUEL COST COEFFICIENTS			EMISSION COEFFICIENTS					GENERATION LIMITS	
	a_i($)	b_i($/MW)	c_i ($/MW^2)	α_i (Ton)	β_i (Ton /p.u.)	γ_i Ton/$pu2$	ε_i TON	δ_i pu^{-1}	p_i^{min} MW	p_i^{max} MW
1	100	200	10	6.49	-5.554	4.091	2.0 e^{-4}	2.857	0.05	0.5
2	120	150	10	5.638	-6.047	2.543	5.0 e^{-4}	3.333	0.05	0.6
3	40	180	20	4.586	-5.094	4.258	1.0 e^{-4}	8.000	0,05	1.00
4	60	100	10	3.380	-3.550	5.326	2.0 e^{-4}	2.000	0.05	1.20
5	40	180	20	4.686	-5.094	4.258	1.0 e^{-4}	8.000	0,05	1,00
6	100	150	10	5.151	-5.555	6.131	1.0 e^{-4}	6.667	0.05	0.60

TABLE AX2

B COEFFICIENT FOR TEST CASE 1

0.02180 0.0170 -0.00036 -0.001100 0.00055 0.00330
0.01070 0.01074 -0.00010 -0.00179 0.00026 0.00280
B_ij= -0.00040 -0.00010 0.02459 -0.01328 -0.011180 -0.00790
-0.00110 -0.00179 -0.01328 0.02650 0.00980 0.00450
0.00055 0.00026 -0.001180 0.00980 0.02160 -0.00010
0.00330 0.00280 -0.00790 0.00450 -0.00010 0.02987

B_{i0}=[0.010731 1.7704 -4.0645 3.8453 1.3832 5.5503] ; B_{00}=0.0014

ANNEXURE 2
FUEL COST COEFFICIENT, EMISSION COST COEFFICIENT AND GENERATION OPERATION LIMIT FOR TEST CASE 2

UNIT	FUEL COST COEFFICIENTS					EMISSION COEFFICIENTS					GENERATION LIMITS	
	a_i ($)	b_i($ /MW)	c_i($ /MW^2)	d_i($)	e_i(rad/MW)	α_i Ton	β_i Ton /p.u.	γ_i Ton/$pu2$	ε_i TON	δ_i pu^{-1}	p_i^{min} MW	p_i^{max} MW
1	0.12951	40.5407	1000.403	33	0.0174	0.04702	-3.9864	360.0012	0.25475	0.01234	10	55
2	0.10908	39.5804	950.606	25	0.0178	0.04652	-3.9524	350.0056	0.25475	0.01234	20	80
3	0.12511	36.5104	900.705	32	0.0162	0.04652	-3.9023	330.0056	0.25613	0.01215	47	120
4	0.12111	39.5104	800.705	30	0.0168	0.04652	-3.9023	330.0056	0.25163	0.01215	20	130
5	0.15247	38.5390	756.799	30	0.0148	0.00420	0.3277	13.8593	0.24970	0.01200	70	240
6	0.10587	46.1592	451.325	20	0.0163	0.00420	0.3277	13.8593	0.24970	0.01200	60	300
7	0.03546	38,3055	1243.531	20	0.0152	0.00680	-0.5455	40.2669	0.24990	0.01203	70	340
8	0.02830	40.3965	1049.998	30	0.0128	0.00680	-0.5455	40.2669	0.24990	0.01203	70	340
9	0.02111	36.3278	1658.569	60	0.0136	0.00460	-0.5122	42,8955	0.24570	0.01234	135	470
10	0.01799	38.2704	1356.659	40	0.0141	0.00460	-0.5112	42.8955	0.24570	0.01234	150	470

ANNEXURE 3
TABLE AX3
B COEFFICIENT FOR TEST CASE 2

0.000049	0.000014	0.000015	0.000015	0.000016	0.00017	0.000017	0.000018	0.000019	0.000020
0.000014	0.000045	0.000016	0.000016	0.000017	0.000015	0.000015	0.000016	0.000018	0.000018
0.000015	0.000016	0.000039	0.000010	0.000012	0.000012	0.000014	0.000014	0.000016	0.000016
0.000015	0.000016	0.000010	0.000040	0.000014	0.000010	0.000011	0.000012	0.000014	0.000015
0.000016	0.000017	0.000012	0.000014	0.000035	0.000011	0.000013	0.000013	0.000015	0.000016
0.000017	0.000015	0.000012	0.000010	0.000011	0.000036	0.000012	0.000012	0.000014	0.000015
0..000017	0.000015	0.000014	0.000011	0.000013	0.000012	0.000038	0.000016	0.000016	0.000018
0.000018	0.000016	0.000014	0.000012	0.000013	0.000012	0.000016	0.000040	0.000015	0.000016
0.000019	0.000018	0.000016	0.000014	0.000015	0.000014	0.000016	0.000015	0.000042	0.000019
0.000020	0.000018	0.000016	0.000015	0.000016	0. 0000015	0.000018	.000016	0.000019	0.000044

ANNEXURE 4
FUEL COST COEFFICIENT, EMISSION COST COEFFICIENT AND GENERATION OPERATION LIMIT FOR TEST CASE 3

UNIT	FUEL COST COEFFICIENTS					EMISSION COEFFICIENTS					GENERATION LIMITS	
	a_i($)	b_i($ /MW)	c_i ($ /MW^2)	d_i($)	e_i(rad/MW)	α_i Ton	β_i Ton /p.u.	γ_i Ton/$pu2$	ε_i TON	δ_i pu^{-1}	p_i^{min} MW	p_i^{max} MW
1	0.00028	8.10	550	300	0.035	0.0632	-2.434	40	0.855	0.0087	0	680
2	0.00056	8.10	309	200	0.042	0.0348	-3.630	50	0.623	0.0068	0	360
3	0.00056	8.10	307	150	0.042	0.0348	-3.630	50	0.623	0.0068	0	360
4	0.00324	7.74	240	150	0.063	0.04376	-5.271	40	.312	0.0085	60	180
5	0.00324	7.74	240	150	0.063	0.04376	-5.271	40	0.312	0.0085	60	180
6	0.00324	7.74	240	150	0.063	0.04376	-5.271	40	0.312	0.0085	60	180
7	0.00324	7.74	240	150	0.063	0.04376	-5.271	40	0.312	0.0085	60	180
8	0.00324	7.74	240	150	0.063	0.04376	-5.271	40	0.312	0.0085	60	180
9	0.00324	7.74	240	150	0.063	0.04376	-5.271	40	0.312	0.0085	60	180
10	0.00284	8.60	126	100	0.084	0.0571	-4.852	100	0.424	0.0052	40	120
11	0.00284	8.60	126	100	0.084	0.0571	-4.852	100	0.424	0.0052	40	120
12	0.00284	8.60	126	100	0.084	0.0571	-4.343	100	1.130	0.0055	55	120
13	0.00284	8.60	126	100	0.084	0.0571	-4.343	100	1.130	0.0055	55	120