# ECONOMIC AND EMISSION LOAD DISPATCH INCLUDING RENEWABLE ENERGY RESOURCES

**Dr.D.Kavitha[1] and C.R.Raashmi[2]**

[1]Assistant Professor, Department of Electrical and Electronic Engineering, Thiagarajar college of Engineering
[2]Department of Electrical and Electronic Engineering, Thiagarajar college of Engineering
Madurai, Tamil Nadu, India
dkavitha@tce.edu

***Abstract***:*The economic load dispatch problem in a power system is to determine the optimal combination of power outputs for all generating units which will minimize the total fuel cost while satisfying all practical constraints. Since optimal economic dispatch is not environmentally the best solution so it is required to reduce the pollution or emission dispatch problem. Here, an attempt has been made to solve the economic-emission load dispatch problem using Cuckoo search algorithm and NSGA II. In single objective best solution easily can be identified by getting the best value from the objective function but in multi objective it is not straight forward hence the Non-dominated sorting is used. In this journal, the EED model is established considering with and without wind power. The Cuckoo Search Algorithm and Non-Dominating Sorting Genetic Algorithms are applied to solve the proposed model. To demonstrate the performance of the improved CSA and NSGA algorithm, the traditional EED problem of the standard IEEE 30-bus 6-generator system is solved and the results obtained by these algorithms show its superior performance. And an important significance test for goodness of fit of theoretical distribution is described by the chi-square test it is also studied for NSGA II to show the algorithm effectiveness and error free solution*

***Keywords:*** *Economic Load Dispatch, Minimize fuel cost and emission, CSA, NSGA II, Chi-square test.*

## I. Introduction

Electric power industry is changing rapidly under the current commercial pressure, determining the operating strategies to meet the demand for electricity, for the specific planning horizon, is one of the most important concerns. Now-a-days major challenge is to satisfy the consumer’s demand for power at minimum cost for any given power system consisting of many generating station, having their own characteristic of operating parameters, are used to meet the total consumer demand. Usually, the cost of operating these generators is not proportional with their outputs therefore the challenge for power utilities is to try to balance the total load among generators.The sizes of electric power system are increasing rapidly to meet the total demand but the rate of increase of generation is less than the rate of increase of power demand hence it is necessary to operate power system in economic manner. This can be done by Economic Load Dispatch techniques. The most common task in power system is to determine and provide an economic condition for generating units without violation of any system constraints, which is known as Economic Load Dispatch (ELD). The parameters must be taken into account for any Economic Load Dispatch problem are load demand and generation cost coefficients. The total operating cost of a power plant depends upon the fuel cost, cost of labor, supplies and maintenance. Generally the costs such as cost of labor, supplies and maintenance being difficult to determine and approximate, hence it is assumed to change as a fixed percentage of the fuel cost. Thus cost function of power plant which is mainly dependent on fuel cost is given as a function of generation.Traditionally the cost function in Economic Load Dispatch problem has been approximated as a quadratic function. The generation cost depends upon the system constraint for a particular load demand it means that the generation cost is not fixed for a particular load demand but depends upon the operating constraint of the sources. In additional, the increasing public awareness of the environmental protection has forced the utilities to modify their operational strategies to reduce the pollution and atmospheric emissions. Hence the classical economic dispatch problem as the emission minimization has gained a lot of attention due to public demand for clean air. There are many traditional optimization methods to solve Economic Load Dispatch problem which require incremental cost curves to be monotonically increasing nature. Now-a-days an alternative to the conventional mathematical approaches, modern heuristic optimization techniques have been given much attention by many researchers due to their ability to find an almost global optimal solution in economic dispatch problem[23].Recently, Xin-She Yang and Suash Deb suggested Cuckoo Search algorithm (CS) which is inspired from the obligate brood parasitic strategy of cuckoo species in combination with the levy flights behavior of birds. The main advantage of cuckoo search algorithm is that it can perform the local search more efficiently and there is only a single parameter apart from the population size. To validate the effectiveness & feasibility of the approach, it has been examined and simulation results obtained are also compared with other reported methodology. The comparison confirms the superiority, fast convergence and proficiency of the algorithm. Then the Multi-Objective optimization algorithm NSGA developed for same test system. The Non-dominated Sorting Genetic Algorithm is a Multiple Objective Optimization (MOO) algorithm and is an instance of an Evolutionary Algorithm from the field of Evolutionary Computation. In single objective best solution easily can be identified by getting the best value from the objective function but in multi objective it is not straight forward hence the Non-dominated sorting is used. NSGA is related to other Evolutionary Multiple Objective Optimization Algorithms (EMOO).In this paper, the EED model is established considering with and without wind power. And the Cuckoo Search Algorithm and Non-Dominating Sorting Genetic Algorithms are applied to solve the proposed model. To demonstrate the performance of the improved CSA and NSGA algorithm, the traditional EED problem of the standard IEEE 30-bus 6-generator system is solved and the results obtained by these algorithms show its superior performance

## II. Problem Description

The economic dispatch (ED) problem is to determine the optimal combination of power outputs for all generating units which minimizes the total fuel cost while satisfying load demand and operational constraints. A number of studies have been presented to solve ED problems. Under the strict governmental regulations on environmental protection, the conventional operation at minimum fuel cost can no longer be the only basis for dispatching electric power. The contributions of the electric energy industry to environmental pollution raise questions concerning environmental protection and methods of reducing pollution from power plants either by design or by operational strategies. Especially, emissions contribution of fossil-fired electric power plants which use coal, oil, gas or combinations as the primary energy resource cannot be neglected. These emissions are CO, CO2, SO2, NO2, particulates, and thermal emission.

Emissions may be reduced through these methods:

i) Switching to fuels with low emission potential,
ii) Installing post-combustion cleaning system, and
iii) Dispatching of generation to each generator unit with the objective of minimum emission dispatch.

Selecting the third method is adequate because it is easy to implement and requires minimal additional costs, so, in this study it is used. Several researchers have considered emissions either in the objective function or treated emissions as additional constraints.

**Objective**

i) Minimization of Fuel Cost
ii) Minimization of Emission

Some researchers have used single objective model for optimizing only the cost but minimization of emission is another very important challenge in Economic Dispatch problem. As there is an increase in emission from thermal units during low and medium power demand periods. Therefore it is also necessary to include emission reduction as an objective in the thermal ED model.

**Generator Operating Cost**

The majority of generators in extant system are of three types: nuclear, hydro and fossil (coal, oil or gas). Nuclear plants are operated at constant output levels and there is essentially no variable operating cost in hydro plants. Therefore, the components of cost which comprise the dispatching procedures are the cost of fuel burnt in the fossil plants. The total cost of operation includes the fuel cost, cost of labour, supplies and maintenance are fixed percentages of incoming fuel cost functions. As the unit loading increases, the input to the unit increases and the incremental heat rate decreases between the opening points for any two valves. However, when the valve is first opened, the throttling loses increases rapidly and the incremental heat rate characteristics are shown in fig. 1

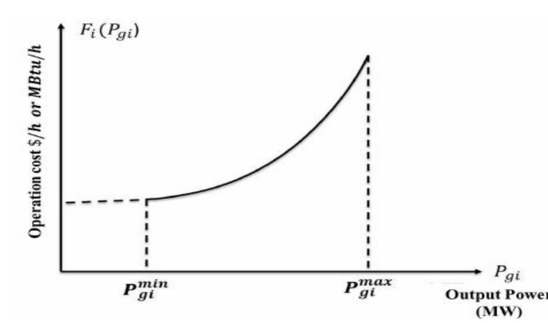


Fig. 1. Operating costs of a fossil- fired generators

$P_{gi}^{min}$is the minimum loading limit below which it is uneconomical (or may be technically infeasible) to operate the unit and $P_{gi}^{max}$ is the maximum output limit.

**Emissions**

In EED problem, emission function is added as a second objective to conventional dispatching problems. This assigns a less power to all such generation units having high emission, and thus emission is reduced. The contribution of the electric energy industry to environment pollution raises questions concerning environmental protection and methods of eliminating or reducing pollution from power plants either by design or by operational strategies from power plants. The two primary power plant emissions from a dispatching are sulfur dioxide ($SO_2$) and nitrogen oxides (NOx). $SO_2$ is dependent on the amount of fuel burned. The sulfur enters the boiler as a part of the fuel. During the combustion process, some of sulfur unites with oxygen from the fuel and the combustion air to form $SO_2$. The remaining sulfur becomes a part of the bottom ash in the boiler. If stack gas clean up equipment is present, most of the $SO_2$ is removed. The remaining $SO_2$ exist the stack as an emission. NOx emissions are more complex. There are two sources ofnitrogen that combine with oxygen from the fuel and the combustion air to produce NOx. The first source is nitrogen in the air that produces an emission called thermal NOx. The second source is nitrogen in the fuel that produces an emission called fuel NOx. In coal, there is no apparent correlation between the amount of fuel-bound nitrogen and the fuel NOx produced.It should be noted that minimizing the emission will not result in the minimum cost. If one switches from minimum cost to minimum emission, generator set points may have to move over a wide range. So, it is not a good idea to do minimum cost dispatch and check the emission, and if it exceeds, then switch to minimum emission dispatch.

**Economic Emission Dispatch with Wind Power**

To reduce the emissions of the power plants, connecting certain renewable energy such as wind power to the power system is another effective approach. Wind energy is clean and renewable energy which is increasingly used in many countries. It has become the world's fastest growing energy source. However, the stochastic nature or uncertainty of the wind speed is considered as a major drawback in using this clean energy source. Integration of wind power also makes the EED problems much more complicated, as it will change the allocation of active power output for the thermal generators. In recent years, some works have been reported for solving the EED problems incorporating wind power generation with the economic and policy incentives, there is a significant growth of wind energy installations in many countries. However, the stochastic nature of wind speed leads to the uncertainty of wind power output. Consequently, the high penetrations of wind power complicate the EED problems significantly. First, the participation of wind power will compensate a portion of load demand and change the allocation of active power output from thermal power units, but the increase or decrease of wind power will not cause acorresponding change in the emission level according to the U-shape of the emission objective function. Second, the stochastic fluctuations in wind power will also increase operating risk of the power system considering the power balance. Therefore, the mathematical model of EED problemin presence of wind power sources will become more complex. A more effective model and method is needed to deal with such Multi Objective Problems in order to obtain quality solutions.

## III. Problem Formulation

**Formulation of Objective Function**

The objective of thermal power system is to find the optimal dispatch by conducting simultaneous minimization of the two objectives, i.e. total operating cost and emission content for a time period consisting of several sub intervals subject to various equality/inequality constraints. First the two objectives are optimized individually using single objective formulation as described in case1 and case 2. Then all the two objectives are simultaneously optimized using multi objective optimization which is also described in case3.

**Case 1:**

MIN Fuel cost = MIN ($\sum_{i=1}^{N} F_i(P_i)$) …. (4.1)Where,

$P_i$ = Real power output of the ith generation.
$F_i(P_i)$ = Generation cost function.

**Case 2:**

MIN Emission = MIN ($\sum_{t=1}^{T} E_{T,t}$) …. (4.2)

$E_{T,i}$ = Environmental cost function.

**Case 3:**

Minimization of both case 1 and case 2 using multi objective optimization techniques

MIN Fuel cost & MIN Emission = MIN ($\sum_{i=1}^{N} F_i(P_i)$) &MIN ($\sum_{t=1}^{T} E_{T,t}$) ….. (4.3)

A system consisting of N thermal generating units connected to a transmission network serving a received electrical load $P_D$ [MW]. The total cost rate of this system is the sum of the cost rate of the individual units. The fuel cost curve is assumed to be approximated by a quadratic function of $P_i$ [MW]

$F_i(P_i) = \sum_{i=1}^{N}(a_i P_i^2 + b_i P_i + c_i)$ [Rs/hr] …. (4.4)Where, $a_i$ [Rs/MW$^2$-h], $b_i$ [Rs/MWh], and $c_i$ [Rs/h] are cost coefficients.

For emission dispatch problem, the amount of $NO_x$ emission is expressed as a quadratic function like the cost function

$$E_{T,i} = \sum_{i=1}^{N}[10^{-2}(\gamma_i P_i^2 + \beta_i P_i + \alpha_i) + \varsigma_i \exp(\varphi_i P_i) \quad [\text{ton/h}] \quad .... (4.5)$$

Where, $\alpha_i$, $\beta_i$, $\gamma_i$, $\varsigma_i$ and $\varphi_i$ are $NO_x$ emission coefficients. Subject to the following operating constraints Equality constraint and Inequality constraints.

**Modeling of Wind Power in Economic Emission Dispatch Problem**

The output power of a wind generator is determined by the stochastic variable wind speed v (m/s). It is well accepted that the probability distribution of the wind speed can be modeled by two-parameter Weibull distribution function such as the probability density function (pdf) and cumulative distribution function (cdf) of the wind speed can written respectively as,

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right], v \geq 0 \quad .... (4.6)$$

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right], v \geq 0 \quad .... (4.7)$$

The output wind power $P_W$ for the given wind speed input v is calculated as

$$P_W = \begin{cases} 0, & v < v_{in} \text{ or } v \geq v_{out} \\ P_{rate}\frac{v - v_{in}}{v_{rate} - v_{in}}, & v_{in} \leq v < v_{rate} \\ P_{rate}, & v_{rate} \leq v < v_{out} \end{cases} \quad .... (4.8)$$

where $P_{rate}$ and $v_{rate}$ are the rated output power and rated wind speed while $v_{in}$ and $v_{out}$ are the cut-in and cut-out wind speed respectively

| $P_{rate}$ | $v_{rate}$ | $v_{in}$ | $v_{out}$ |
|---|---|---|---|
| 0.3p.u | 45m/s | 5m/s | 15m/s |

**Operating Constraints**

**i) Equality constraint for demand-generation balance**

The total thermal generated powers should be equal to the sum of demand at any given time t as shown below

$$P_{Load} - \sum_{i=1}^{n} P_i = 0 \quad .... (4.9)$$

Where,
n number of generators connected in the network
P load total load of the system.
Pi real power generation of ith generator.

**ii) Inequality constraints due to thermal generator operating limits**

The decision variable $P_i^t$ must be between the specified maximum and minimum power limit $P_i^{min}$ and $P_i^{max}$. The dispatch power should satisfy the following inequality constraint given by:

$$P_i^{min} < P_i < P_i^{max} \quad .... (4.10)$$

Where,
Pi min minimum value of real power allowed at generator i
Pi max maximum value of real power allowed at generator i

## IV. Methodology

During last few years, many nature inspired evolutionary algorithms have been developed for optimization. These algorithms work on the basis of random search in some suitable search region depending on the problem. Though it is a random search, it is not truly random because there is a mechanism in the algorithm which guides the search in such a manner that the solution vector gets improved step by step. Such algorithms have become quite popular and helping due to their efficiency in terms of robustness, accuracy, speed and simple implementation. But at the same time, they have some drawbacks like, one particular algorithm may be efficient for a specific class of optimization problems but may not be so efficient for some other class of optimization problems or sometimes they get stuck into local optimum. One of such nature inspired algorithms is Cuckoo Search algorithm (CS).

The Non-dominated Sorting Genetic Algorithm is a Multiple Objective Optimization (MOO) algorithm and is an instance of an Evolutionary Algorithm from the field of Evolutionary Computation. NSGA is an extension of the Genetic Algorithm for multiple objective function optimizations. It is related to other Evolutionary Multiple Objective Optimization Algorithms such as the Vector-Evaluated Genetic Algorithm, Strength Pareto Evolutionary Algorithm, and Pareto Archived Evolution Strategy.

**Cuckoo Search Algorithm (CS)**

The algorithm was developed by Xin-She Yang and Suash Deb in 2009. It was inspired by obligate brood parasitism of some cuckoo species by laying their eggs in to the nest of host birds. Those female parasitic cuckoos can imitate the colors and pattern of the eggs of the host species. So there are fewer chances that the host bird may identify and destroy the eggs. But, by chance, if the host bird discovers that the eggs are different, it will either destroy the eggs or may destroy the nest completely and build a new nest at different place. The timing of egg-laying of some species is also amazing. The parasitic cuckoo often chooses a host nest where the eggs are just laid. In general, the cuckoo eggs are hatched little earlier than the host eggs. As soon as the first cuckoo chick is hatched, it starts throwing out the host eggs blindly out of the nest so that it can increase the share of its food provided by the host bird. The animals search for food in random manner. Their search path is made up of step by step random walk or flight which is based on the current location and the transition probability to the next location. Various studies show that the flight behavior of animals or birds has typical characteristics of Lévy flight. Lévy flight is a random walk where the step size is distributed according to the heavy tailed distribution. After a large number of steps, the distance from the origin of the flight tends to a stable distribution.

**Cuckoo Search via Lévy flights**

The algorithm works on the basis of following three assumptions:

i) A cuckoo chooses a nest randomly to lay the egg and at a time only one egg is laid by the cuckoo
ii) The best nests with the high quality egg (solution) will carry over to the next generations.
iii) The total number of available host nests is fixed and the host bird can discover a cuckoo's egg with a probability,

$Pa \in$ 0, 1 . In this case, the host bird either destroys the egg or Towards the Improvement of Cuckoo Search Algorithm destroys the nest completely and builds up a new nest somewhere else. The third assumption can be approximated as a switching probability (*Pa)* of the total *n* nests that are replaced by the new nests having a new random solution. When generating new solution $\boldsymbol{Xt}+\mathbf{1}$ for, say, a cuckoo $\boldsymbol{i}$,a Levy flight is performed as

$$\boldsymbol{Xit}+\mathbf{1} = \boldsymbol{Xit} + \boldsymbol{\alpha} \oplus \boldsymbol{L}é\boldsymbol{vy\lambda}$$

Where α > 0 is the step size which should be related to the scales of the problem of interests. In most cases, α = 1 is used. This equation is stochastic equation for random walk. In general, a random walk is a Markov chain whose next location depends only on the current location and the transition probability. The product ⊕ means entry wise multiplications. The Lévy flight essentially provides a random walk while the random step length is drawn from a Lévy distribution Lévy~ $u = t-$, ($1 < \lambda \leq 3$) which has an infinite variance with an infinite mean. Here the steps essentially form a random walk process with a power law step length distribution with a heavy tail. The algorithm canalso be extended to more complicated cases where each nest contains multiple eggs (a set of solutions).

**Pseudo code for Cuckoo Search Algorithm**

**Begin**
Objective function f(x), x = (x1,...xd) T
Generate initial population of
n host nests xi (i = 1, 2, ..., n)
**while** (t < Max Generation) or (Stop criterion)
Get the cuckoo randomly by Levy flights
Evaluate its quality/fitness Fi
Choose the nest among n (say j) randomly
**If** (Fi >Fj)
replace j by the new solution;
**end**
A fraction (pa) of worse nests
are abandoned and new ones are built;
Keep the best solutions
(or nests with quality solutions);
Rank the solutions and find the current best
**end while**
Post process results and visualization
**End**

**Non-Dominated Sorting Genetic Algorithm II**

The Non-dominated Sorting Genetic Algorithm is a Multiple Objective Optimization (MOO) algorithm and is an instance of an Evolutionary Algorithm from the field of Evolutionary Computation. NSGA implements elitism for multi-objective search, using an elitism-preserving approach. Elitism is introduced by storing all non-dominated solutions discovered so far, beginning from the initial population. Elitism enhances the convergence properties towards the Pareto-optimal set.A parameter-less diversity preservation mechanism is adopted. Diversity and spread of solutions are guaranteed without the use of sharing parameters, since NSGA adopts a suitable parameter-less niching approach. It uses the crowding distance, which estimates the density of solutions in the objective space, and the crowded comparison operator, which guides the selection process towards a uniformly spread Pareto-frontier.

The objective of the NSGA algorithm is to improve the adaptive fit of a population of candidate solutions to a Pareto front constrained by a set of objective functions.

**Implementation of NSGA II**

A general NSGA II procedure to be implemented in the following steps:
Step 1: Create a random parent population, Pn of size Z.
Step 2: Sort the random parent population based on non-domination.
Step 3:For each non-dominated solution, assign a fitness (rank) equal to its non-domination level (1 is the best level, 2 is the next best level, and so on).
Step 4: Create an offspring population, Qn of size Z using binarytournament selection, recombination, and mutation operators.
Step 5: From the first generation onwards, creation of each new generation constitutes the following steps:

i) Create the mating pool Rn, of size 2Z by combining the parent population, Pnand the offspring population, Qn.

ii) Sort the combined population, Rn, according to the fast non-dominated sorting procedure to identify all non-dominated fronts (F1, F2, . . . ,Fl).
iii) Generate the new parent population, Pn+ 1 of size Z by adding non-dominated solutions starting from the first ranked non-dominated front, F1. When the total non-dominated solutions exceed the population size Z, reject some of the lower ranked non-dominated solutions. This is achieved through a sorting procedure which is done according to the crowded comparison operator based on the crowding distance.Perform the selection, crossover and mutation operations on the newly generated parent population, Pn+1 to create the new offspring population, Qn+1 of size Z.

Step6:Repeat Step 5 until the maximum number of iterations is reached.

**Chi-Square: Testing for Goodness of fit**

The statistical inference has been concentrated on statistics such as the mean and the proportion. These summary statistics have been used to obtain interval estimates and test hypotheses concerning population parameters. Here it changes the approach to inferential statistics somewhat by examining whole distributions, and the relationship between two distributions. In doing this, the data is not summarized into a single measure such as the mean, standard deviation or proportion. The whole distribution of the variable is examined, and inferences concerning the nature of the distribution are obtained. Here, these inferences are drawn using the chi square distribution and the chi square test. The first type of chi square test is the goodness of fit test. The chi square test is the most useful and most widely used tests in statistics

**Goodness of fit for discrete distributions**

Goodness of fit involves a comparison of the frequency observed in the sample with the expected frequency based on some theoretical model. If the differences between the observed and the expected frequencies are so great that they are unlikely to be due to chance alone, we conclude that the sample is not taken from the population that was used to calculate the expected frequencies. Suppose we have j observed frequencies, O1, O2, ... On and their corresponding expected frequencies, E1, E2, ..., En, then the expression

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)}{E_i}$$

is approximately χ2 distributed with n-1 degrees of freedom. The closer the agreement between the observed and expected values, the smaller will be the value of χ2, and a value of zero indicates perfect agreement. Calculated values of χ2 exceeding those in Chi square Table indicate that, at the corresponding probability level, there is significant disagreement between observed and expected values.

**Chi Square Calculation**

Each entry in the summation can be referred to as “The observed minus the expected, squared, and divided by the expected.” The chi square value for the test as a whole is “The sum of the observed minus the expected, squared, and divided by the expected.”

## V. Results and Discussions

The proposed methodology for solving EED problem has been tested on IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA.The comparative study is made for the six units system for fuel cost ($/h) and emission (ton/h) using cuckoo search algorithm with the result obtained from ref [35] by considering without and with wind power are explained in case1 and case2 respectively. And the Multi-Objective optimization algorithm NSGA II is developed for same test system. An important significance test for goodness of fit of theoretical distribution is described by the chi-square test it is also studied for NSGA II.

**Case 1: IEEE 30 bus six-generator system without wind power**

Table 2: Economic Dispatch problem using cuckoo search algorithm
Table 3: Emission Dispatch problem using cuckoo search algorithm
Table 4: Comparison of result obtained from Table 2 & Table 3 with ref [35]
Table 5: Multi objective EED problem using NSGA II
Table 6: Chi Square Test for Fuel cost obtained from NSGA II optimization technique
Table 7: Chi Square Test for Emission obtained from NSGA II optimization technique

**Case 2: IEEE 30 bus six-generator system with wind power**

Table 8: Economic Dispatch problem using cuckoo search algorithm
Table 9: Emission Dispatch problem using cuckoo search algorithm
Table10: Comparisonof result obtained from Table 8 & Table 9 with ref [35]
Table11: Multi objective EED problem using NSGA II
Table12: Chi Square Test for Fuel cost obtained from NSGA II optimization technique
Table13: Chi Square Test for Emission obtained from NSGA II optimization technique

**Test System**

Table 1 Cost and Emission coefficient

| Units | Cost | | | Emission | | | | | Upper limits(p.u) | Lower limits(p.u) |
|---|---|---|---|---|---|---|---|---|---|---|
| | ai | bi | ci | $\alpha_i$ | $\beta_i$ | $\gamma_i$ | $\zeta_i$ | $\varphi_i$ | | |
| $G_1$ | 10 | 200 | 100 | 4.091 | -5.554 | 6.490 | 2.0e-4 | 2.857 | 0.5 | 0.05 |
| $G_2$ | 10 | 150 | 120 | 2.543 | -6.047 | 5.638 | 5.0e-4 | 3.333 | 0.6 | 0.05 |
| $G_3$ | 20 | 180 | 0 | 4.258 | -5.094 | 4.586 | 1.0e-6 | 8.000 | 1.0 | 0.05 |
| $G_4$ | 10 | 100 | 60 | 5.326 | -3.550 | 3.380 | 2.0e-3 | 2.000 | 1.2 | 0.05 |
| $G_5$ | 20 | 180 | 40 | 4.258 | -5.094 | 4.586 | 1.0e-6 | 8.000 | 1.0 | 0.05 |
| $G_6$ | 10 | 150 | 100 | 6.131 | -5.555 | 5.151 | 1.0e-5 | 6.667 | 0.6 | 0.05 |

## Results

### Case 1: IEEE 30 bus six-generator system without wind power

The proposed methodology CSA and NSGA is applied for solving EED problem and it has been tested on IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by considering without wind power.

Table 2 Economic Dispatch problem using cuckoo search algorithm

| UNITS | **Cuckoo Search Algorithm**<br>Best Fuel cost |
|---|---|
| $G_1$(p.u) | 0.1124 |
| $G_2$(p.u) | 0.2743 |
| $G_3$(p.u) | 0.3710 |
| $G_4$(p.u) | 1.0044 |
| $G_5$(p.u) | 0.6121 |
| $G_6$(p.u) | 0.4598 |
| Cost ($/h) | **602.4481** |
| Emission(ton/h) | 0.2284 |

Table 2 Listed the best optimal output power of generators and fuel cost ($/h) for economic load dispatch problem using proposed Cuckoo search method with Std. IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by considering without wind power and using parameters levy=0.01, Pa=0.3,Population=50 and generation=100.

Fig. 2, shows the convergence characteristics of best fuel cost obtained for Std. IEEE 30 bus six-generator systemby considering without wind power with the population=50 and generation=100.

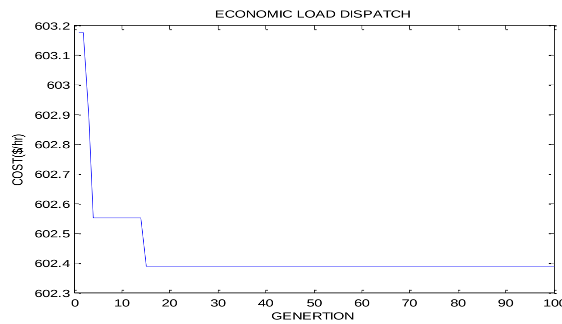


Fig. 2.convergence curve for best fuel cost ($/h) on case1

Table3 Emission Dispatch problem using cuckoo search algorithm

| UNITS | **Cuckoo Search Algorithm**<br>Best Emission |
|---|---|
| $G_1$(p.u) | 0.4843 |
| $G_2$(p.u) | 0.5008 |
| $G_3$(p.u) | 0.5749 |
| $G_4$(p.u) | 0.2905 |
| $G_5$(p.u) | 0.5629 |
| $G_6$(p.u) | 0.4211 |
| Cost ($/h) | 625.78 |
| Emission(ton/h) | **0.1928** |

Table 3, Listed the best optimal output power of generators and Best Emission(ton/h) for emission load dispatch problem using proposed Cuckoo search method with Std. IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by considering without wind power and using parameters levy=0.01, Pa=0.3,Population=50 and generation=70.

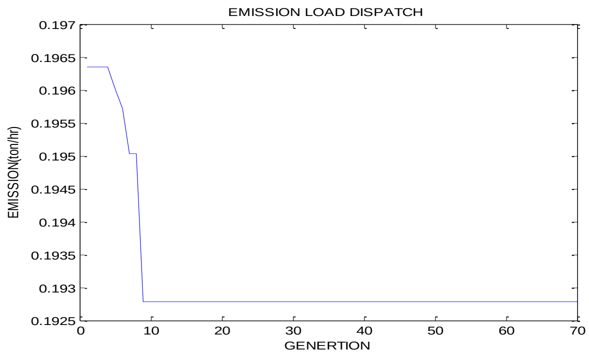


Fig. 3.Convergence curve for best emission (ton/h) on case1

Fig. 3, shows the convergence characteristics of best fuel cost obtained for Std. IEEE 30 bus six-generator systemby considering without wind power with the population=50 and generation=70.

Table 4 comparison of result obtained from Table 2 and Table 3 with ref [35]

| UNITS | **Ref (35)** | | **Cuckoo Search Algorithm** | |
|---|---|---|---|---|
| | Best Fuel cost | Best Emission | Best Fuel cost | Best Emission |
| $G_1$(p.u) | 0.1792 | 0.4056 | 0.1124 | 0.4843 |
| $G_2$(p.u) | 0.3712 | 0.4594 | 0.2743 | 0.5008 |
| $G_3$(p.u) | 0.6939 | 0.5502 | 0.3710 | 0.5749 |
| $G_4$(p.u) | 0.5905 | 0.3852 | 1.0044 | 0.2905 |
| $G_5$(p.u) | 0.5889 | 0.5453 | 0.6121 | 0.5629 |
| $G_6$(p.u) | 0.4354 | 0.5181 | 0.4598 | 0.4211 |
| Cost ($/h) | **619.53** | 644.98 | **602.4481** | 625.78 |

From Table 4 , it is inferred that the Best Fuel cost and Best Emission obtained from the cuckoo search algorithm is optimal when compared with result from ref[35] for Std. IEEE 30 bus six-generator system by considering without wind power and by using parameter levy=0.01, Pa=0.3,Population=50 and generation=70. From this it is observed that the use of Cuckoo Search Algorithm is more effective. Table 6.5 Listed the best optimal output power of generators for Best Fuel cost ($/h) and Best Emission (ton/h) considering economic and emission load dispatch problem using multi objective optimization NSGA II algorithm with Std. IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by considering without wind power and using parameters Population=50 and generation=500

Table 5 Multi objective EED problem using NSGA II

| UNITS | **NSGA II** | |
|---|---|---|
| | Best Fuel cost | Best Emission |
| $G_1$(p.u) | 0.13469 | 0.38541 |
| $G_2$(p.u) | 0.30945 | 0.48841 |
| $G_3$(p.u) | 0.53580 | 0.57056 |
| $G_4$(p.u) | 0.96128 | 0.38715 |
| $G_5$(p.u) | 0.48120 | 0.47686 |
| $G_6$(p.u) | 0.41156 | 0.52561 |
| Cost ($/h) | **600.71** | 638.65 |
| Emission(ton/h) | 0.22198 | **0.19199** |

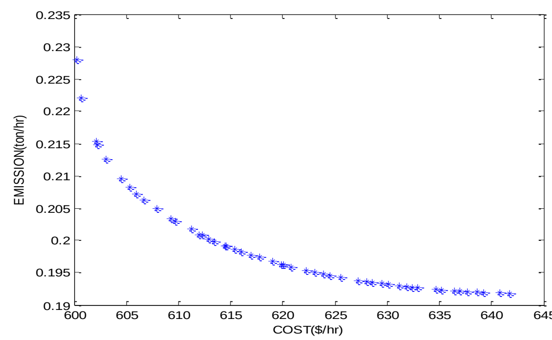


Fig. 4. Pareto front set in Test system without wind power

Fig. 4, depicts the Pareto optimal front utilizing NSGA II technique. In this case, the Pareto front is obtained for IEEE 30-bus test system without wind power.

**Chi Square Test**

From Table 6 and 7, it is inferred that the NSGA optimization technique solved for Economic Emission Load Dispatch without wind power and chi square test is analyzed for the goodness of fit of the solution for various no. of samples, from this it is observed as Chi Square calculated $\mathcal{X}^2$ is less than Chi Square From table$\mathcal{X}_0^2$. Hence it can be concluded that applied NSGA technique gives the solution more effective and error free results.

Table 6 Chi Square Test for Fuel cost obtained fromNSGA II technique

| No. Samples (n) | Degree of freedom (v = n-1) | Significance value (%) | Chi Square calculated $\mathcal{X}^2$ | Chi Square From table A.I.1 $\mathcal{X}_0^2$ |
|---|---|---|---|---|
| 30 | 29 | 0.05 | 0.0034770 | 42.557 |
| 25 | 24 | 0.05 | 0.0045167 | 36.415 |
| 20 | 19 | 0.05 | 0.0066568 | 30.144 |
| 15 | 14 | 0.05 | 0.0038378 | 23.685 |
| 10 | 9 | 0.05 | 0.0019664 | 16.9194 |

Table 7Chi Square Test for Emission obtained from NSGA II technique

| No. Samples (n) | Degree of freedom (v = n-1) | Significance value (%) | Chi Square calculated $\chi^2$ | Chi Square From table A.I.1 $\chi_0^2$ |
|---|---|---|---|---|
| 30 | 29 | 0.05 | $4.74x10^{-5}$ | 42.557 |
| 25 | 24 | 0.05 | $3.51x10^{-5}$ | 36.415 |
| 20 | 19 | 0.05 | $2.84x10^{-5}$ | 30.144 |
| 15 | 14 | 0.05 | $1.83x10^{-5}$ | 23.685 |
| 10 | 9 | 0.05 | $7.48x10^{-6}$ | 16.9194 |

**Case 2: IEEE 30 bus six-generator system with wind power**

The proposed methodology CSA and NSGA is applied for solving EED problem and it has been tested on IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by considering with wind power and the output wind power $P_W$ for the given wind speed input v is calculated as from (4.8)

Table 8 Economic Dispatch problem using cuckoo search algorithm

| UNITS | **Cuckoo Search Algorithm**<br>Best Fuel cost |
|---|---|
| $G_1$(p.u) | 0.12104 |
| $G_2$(p.u) | 0.31470 |
| $G_3$(p.u) | 0.52082 |
| $G_4$(p.u) | 1.03340 |
| $G_5$(p.u) | 0.37532 |
| $G_6$(p.u) | 0.39020 |
| $P_W$(p.u) | 0.07800 |
| Cost ($/h) | **583.73** |
| Emission(ton/h) | 0.2277 |

Table 8 Listed the best optimal output power of generators and fuel cost ($/h) for economic load dispatch problem using proposed Cuckoo search method with Std. IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by considering without wind power and using parameters levy=0.01, Pa=0.3,Population=50 and generation=100.

Fig. 5, shows the convergence characteristics of best fuel cost obtained for Std. IEEE 30 bus six-generator systemby considering with wind power with the population=50 and generation=100.

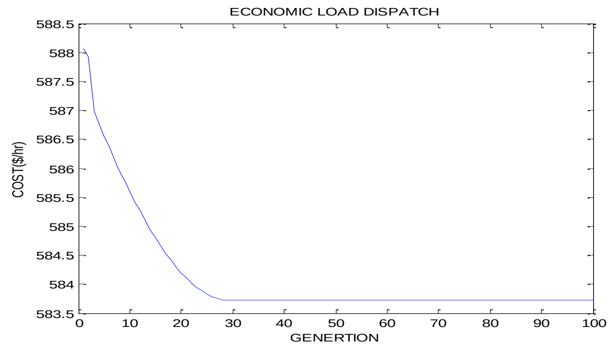


Fig. 5.Convergence curve for best fuel ($/hr) cost on case2

Table 9 Emission Dispatch problem using cuckoo search algorithm

| UNITS | **Cuckoo Search Algorithm**<br>Best Emission |
|---|---|
| $G_1$(p.u) | 0.3299 |
| $G_2$(p.u) | 0.5608 |
| $G_3$(p.u) | 0.5400 |
| $G_4$(p.u) | 0.1847 |
| $G_5$(p.u) | 0.5516 |
| $G_6$(p.u) | 0.6000 |
| $P_W$(p.u) | 0.1152 |
| Cost ($/h) | 610.35 |
| Emission(ton/h) | **0.1925** |

Table 9 Listed the best optimal output power of generators and Best Emission(ton/h) for emission load dispatch problem using proposed Cuckoo search method with Std. IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by considering with wind power and using parameters levy=0.01, Pa=0.3,Population=50 and generation=100.

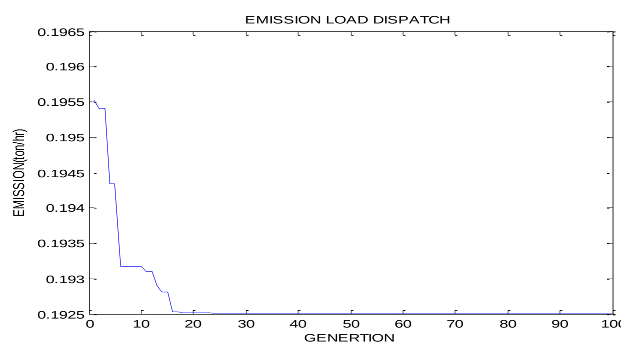


Fig. 6.Convergence curve for best emission (ton/hr) on case2

Fig. 6, shows the convergence characteristics of best emission obtained for Std. IEEE 30 bus six-generator systemby considering without wind power with the population=50 and generation=100.

Table 10 Comparison of result obtained from Table 8 & Table 9 with ref [35]

| UNITS | **Ref (35)** | | **Cuckoo Search Algorithm** | |
|---|---|---|---|---|
| | Best Fuel cost | Best Emission | Best Fuel cost | Best Emission |
| $G_1$(p.u) | 0.0738 | 0.4033 | 0.12104 | 0.3299 |
| $G_2$(p.u) | 0.2942 | 0.4322 | 0.31470 | 0.5608 |
| $G_3$(p.u) | 0.4950 | 0.5422 | 0.52082 | 0.5400 |
| $G_4$(p.u) | 0.9323 | 0.3720 | 1.03340 | 0.1847 |
| $G_5$(p.u) | 0.6171 | 0.5241 | 0.37532 | 0.5516 |
| $G_6$(p.u) | 0.3443 | 0.5109 | 0.39020 | 0.6000 |
| $P_W$(p.u) | 0.0773 | 0.0492 | 0.07800 | 0.1152 |
| Cost ($/h) | **583.92** | 627.11 | **583.73** | 610.35 |
| Emission (ton/h) | 0.2195 | **0.1943** | 0.2277 | **0.1925** |

From Table 10, it is inferred that the Best Fuel cost and Best Emission obtained from the cuckoo search algorithm is optimal when compared with result from ref[35] for Std. IEEE 30 bus six-generator system by considering with wind power and by using parameter levy=0.01, Pa=0.3,Population=40 and generation=100. From this it is observed that the use of Cuckoo Search Algorithm is more effective.

Table 11 Multi objective EED problem using NSGA II

| UNITS | **NSGA II** | |
|---|---|---|
| | Best Fuel cost | Best Emission |
| $G_1$(p.u) | 0.15050 | 0.38962 |
| $G_2$(p.u) | 0.33325 | 0.51026 |
| $G_3$(p.u) | 0.51845 | 0.55031 |
| $G_4$(p.u) | 0.91533 | 0.36623 |
| $G_5$(p.u) | 0.47967 | 0.49801 |
| $G_6$(p.u) | 0.35829 | 0.44107 |
| $P_W$(p.u) | 0.07850 | 0.07850 |
| Cost ($/h) | **583.68** | 621.90 |
| Emission (ton/h) | 0.21874 | **0.19223** |

Table 6.11 Listed the best optimal output power of generators for Best Fuel cost($/h) and Best Emission(ton/h) considering economic and emission load dispatch problem using multi objective optimization NSGA II algorithm with considering with wind power and using parameters Population=50 and generation=500.

Std. IEEE 30 bus six-generator system with total load demand 2.834 p.u where the base is 100MVA by

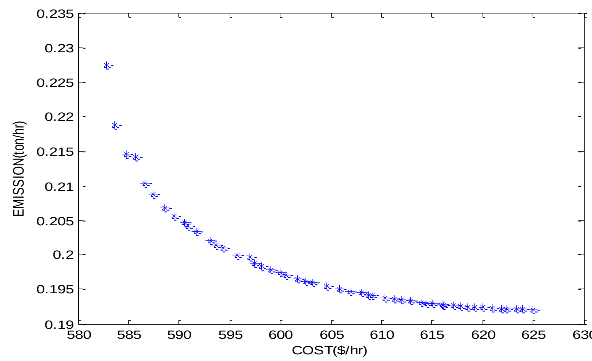


Fig. 7.Pareto front set in Test system with wind power

Fig. 7, depicts the Pareto optimal front utilizing NSGA II technique. In this case, the Pareto front is obtained for IEEE 30-bus test system with wind power.

### Chi Square Test

Table 12 Chi Square Test for Fuel cost obtained from NSGA II technique

| No. Samples (n) | Degree of freedom (v = n-1) | Significance value (%) | Chi Square calculated $\chi^2$ | Chi Square From table A.I.1 $\chi_0^2$ |
|---|---|---|---|---|
| 30 | 29 | 0.05 | 0.000457 | 42.557 |
| 25 | 24 | 0.05 | 0.000417 | 36.415 |
| 20 | 19 | 0.05 | 0.000467 | 30.144 |
| 15 | 14 | 0.05 | 0.000241 | 23.685 |
| 10 | 9 | 0.05 | 0.000222 | 16.9194 |

Table 13Chi Square Test for Fuel cost obtained from NSGA II technique

| No. Samples (n) | Degree of freedom (v = n-1) | Significance value (%) | Chi Square calculated $\chi^2$ | Chi Square From table A.I.1 $\chi_0^2$ |
|---|---|---|---|---|
| 30 | 29 | 0.05 | $3.159 \times 10^{-5}$ | 42.557 |
| 25 | 24 | 0.05 | $2.721 \times 10^{-5}$ | 36.415 |
| 20 | 19 | 0.05 | $2.421 \times 10^{-5}$ | 30.144 |
| 15 | 14 | 0.05 | $2.280 \times 10^{-5}$ | 23.685 |
| 10 | 9 | 0.05 | $2.123 \times 10^{-5}$ | 16.9194 |

From Table 12 and 13, it is inferred that the NSGA optimization technique solved for Economic Emission Load Dispatch with wind power and chi square test is analyzed for the goodness of fit of the solution for various no. of samples, from this it is observed as Chi Square calculated $\mathcal{X}^2$ is less than Chi Square From table$\mathcal{X}_0^2$. Hence it can be concluded that applied NSGA technique gives the solution more effective and error free results.

## VI. Conclusion

The proposed Cuckoo Search Algorithm and NSGA have been implemented successfully to solve the Economic-Emission Load Dispatch problem of units by considering without and with wind power which are explained in case1 and case2 respectively. Cuckoo Search Algorithm and NSGA II is tested IEEE 30 bus six-generator system.The Results obtained by the Cuckoo Search Algorithm for Economic Emission Dispatch problem is compared with the result from Ref [35] for both cases. Then the Multi-Objective optimization algorithm NSGA II developed for same test system which is also for both cases. And an important significance test for goodness of fit of theoretical distribution is described by the chi-square test it is also studied for NSGA II to show the algorithm effectiveness and error free solution. The program is written in MATLAB software package. The Economic Load Dispatch has to meet the load demand at minimum operating cost while satisfying the constraints of power system of all units.

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