Soft Computing Technique for Optimal Load Dispatching and Renewable Power Estimation using Probability Density Function

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Abstract- In this modern era, Economic Load Dispatch (ELD) plays an important role in power systems and planning. The main object of this problem is to diminish the cost of fuel of generator units. In this research, ELD problem is implemented and discussed with Cuckoo Search, Harmony Search and Firefly Algorithm (FA) for some non-linear benchmark functions to highlight the efficiency of algorithm. Then, renewable sources have been included in ELD problem. These sourses estimating by using probability density function with overestimation and underestimation cost for wind and solar units included. In this problem we took assumption that load is located near the renewable power plant so that we can neglect the transmission losses and considering only for the thermal units. The problem is imposed over the four test cases with different combinations of renewable sources and evaluated with the help of MATLAB coding for algorithms. The result clearly shows that Cuckoo Search provides accurate solution when compared with other optimization algorithms.

Keywords: Economic load dispatch, cuckoo search algorithm, weibull's probability density function, renewable energy, solar power, wind power, overestimation cost and underestimation cost.

I. Introduction

In power system operation, economic load dispatch (ELD) is one of the more important real time problems. The main objective of ELD problem is to minimize the fuel cost of generating units. In the case of increasing fuel demand, there is a need to find out an optimized solution for reducing generating cost with different generating units in power system. To resolve ELD problem, there are many approaches and strategies have been developed and adopted like gradient method, linear and non-linear programming, quadratic and dynamic programming etc. These all methods are involving only massive efforts in computation. ELD has developed critical fundamental features in power system operation and control.

To avoid many complexities in computing, some artificial intelligent algorithm has been developed to get best solution like,GA,PSO, artificial bee colony optimization and bacterial foraging etc. Currently, Bio-inspired algorithms have given good performance in managing with some non linear optimization problems for allocating the premier solution. In the same pipeline, Cuckoo search (CS) is one of the new metaheuristic optimization algorithm which is developed by Suash Dev and Xin-She Yang in year 2009 [1]. Economic load dispatch analysis had been studied by many researches and get the nearest optimum result in the generating power of each generator using CSA and it was found that the CSA is more robust and efficient in determining the optimal load scheduling.

In the coastal plains, wind power has huge possibility of expansion in India especially. In India winds are influenced by strong south-west summer monsoon in months of April to September where as weakest in north-east winter monsoons. Total 1100 wind monitoring stations are established in India with 33 states/UTs, also it was estimated that 233 sites with annual average wind power density to be greater than 200 Watts/m^2. In future wind power growth in India is estimated to be around 1,00,000 MW. In India, there is a big demand of the solar generation

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because of the high solar irradiance index and also a very high predictable life of a solar power plant. Recently there are many projects in progress employing solar power generation in Rajasthan, Gujarat and other regions of the country [2].

Distributed generation with renewable sources of energy has been playing a major role in both industry and research of late. It reduces the emissions and provides the wider choice of power generation choices. Today wind and solar sources of power generation are faster growing renewable energy sources which are highly environment friendly. The hybrid system of power generation comprehend various power sources implicating the fossil fuel fired generators, wind energy conversion system and solar power generating system. Both these renewable power sources are dependent on weather and geographical conditions. Probabilistic technique can be used to calculate the solar irradiance and wind speed variability. Modeling of wind speed and solar irradiance by probability density function provides key parameters which can show the characteristics of solar irradiance and wind speed . The penalties are imposed on the over generation and under generation of power on the generating unit companies which are being included in the operating cost of renewable power generating units. The penalty varies regionally, depending upon the policies of the particular region. After the adding of renewable sources in load dispatch problem along with conventional coal fired generating units then it reduces fuel cost, emission/pollution and transmission losses in the system. The proposed method in this dissertation will also encourage the utilization of renewable sources of energy.

II. Economic Load Dispatch

The main motive of economic load dispatch problem is to decrease the overall fuel cost of generating units along with satisfying the equality and inequality constraints. In a complex electrical system, various generators are implemented and supply the required output to satisfy consumer demand [3]. Generally each units has a unique characteristic that is cost-per-hour. The total cost for generators consider mainly as cost of fuel , labor cost and cost of maintenance etc. But for simplicity usually fuel cost is considered. For hydro power plants, the fuel is free so fuel cost is zero. The output power of thermal plants improved with steam valve opening to the turbines inlet. The cost of fuel is usually a quadratic function and can be given as:

$$F(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i \quad Rs/Hr \tag{1}$$

Where, the a_i, b_i and c_i are the generator constant coefficients of cost. From equation (1), $F_i(P_{gi})$ is the fuel cost of the i^{th} generating unit, expressed in the Rs/hr. the total cost of the system for N units will be given by-

$$F_T = F_1 + F_2 + \dots\dots\dots + F_N \tag{2}$$

The objective function for the problem can be defined as given below

$$\text{Min } F_T = \sum_{i=1}^{N} F_i(P_{gi}) \tag{3}$$

Further the constraints can be categorized in to two categories:

1. Constraints for equality
2. Constraints for Inequality

Constraints for equality: The reactive power demand did not influence the cost function[4]. The net power balance equation can be defined as:

$$P_d = \sum_{i=1}^{N} P_{gi} \tag{4}$$

Also, the transmission losses are neglected in equation (4), but if they are included then equation (4) will get change and modified as:

$$P_d + P_L = \sum_{i=1}^{N} P_{gi} \tag{5}$$

Where, P_L and P_d are the transmission losses and total load demanded respectively.

Furthermore the transmission loss can be calculated as,

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{N} P_{gi} B_{0i} + B_{00} \tag{6}$$

Where, the B_{ij}, B_{0i} and B_{00} are known as B-coefficients.

Constraints for inequality: Constraints for Inequality are categorized into transmission loss constraints and generator constraints describe as :

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \tag{7}$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \tag{8}$$

$$P_L > 0 \tag{9}$$

Where, P_{gi}^{max} and P_{gi}^{min} are the maximum and minimum real power generation limits of i^{th} unit respectively.

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Similarly, Q_{gi}^{max} and Q_{gi}^{min} are the maximum and minimum reactive power generation limits of i^{th} unit respectively.

The renewable energy sources are available in huge quantity in nature or environment like. solar, wind, ocean, geothermal , biomass, tidal energy etc. All renewable energy can be converted into different form of useful energy like mechanical electrical, chemical and thermal energy etc. through various energy conversion systems. Also, electrical energy is highest demanded form of energy and many researches are working to harness more electrical energy from these renewable sources.

The economic load dispatch problem will reduce the generation load on the thermal and other fossil fuel fired units with the including of the renewable energy sources [5]. In this problem explanation , considering only the Photo voltaic system (PVS) and wind energy conversion system (WECS) with the thermal units in the economic dispatch problem adding factors of both underestimation and overestimation of the available power of wind and solar.

III. Cuckoo Search Algorithm

This algorithm (CSA) is one of the new metaheuristic optimization algorithm which is developed in the year 2009 by Suash Deb of C.V. Raman College of Engineering and Xin-She Yang of Cambridge University. CSA was inspired by the obligate flock parasitism of the some cuckoo bird which lay eggs in the nest of some other host birds, even through at time they also the remove the already existing eggs. This increases the probability of hatching of their own eggs[6]. CS idealizes this type of breeding behavior and hence it can be applied for several optimization problems. It look that it can perform better than other met heuristic algorithms in applications. In addition to that the egg laying timing of some bird is extremely amazing. Parasitic cuckoos often choose nests where eggs have just seen laid by the host bird.

. In simple way, the cuckoo's eggs hatch slightly earlier host eggs [7]. Once the first female cuckoo hatches, the first naturally taken action will make throw out of the host eggs by blindly propelling the eggs out from the nest, which is increase the share of female cuckoo's food which is provided by host bird. After Studies it was found that female cuckoo can also imitate the voice of host female bird to gain the more feeding opportunity.

To describe our new cuckoo search, the following three idealized rules can be used

1) Each cuckoo bird lays only one egg in one time, and it dumps it egg in a nest which is randomly chosen.

2) For next generations, the nests which have a good quality of eggs will be carried.

3) The available host nest is fixed and the egg those laid by cuckoo is found by the host bird with a probability p_a € [0,1].

On further approximation, this final estimation can be approximation by a ratio p_a of the n host nest and replaced by new nest it means with new random solution .

For a problem of maximization, the fitness or quality of a solution can be proportional to the objective function value. In other words, fitness can be defined in same way to the fitness function in genetic algorithms [8].

For the extention point of view, we can use simple representation which follows that every single egg in a nest denotes a single solution, and each cuckoo could lay just one egg (therefore representing a single solution), the aim is to use the new best solutions in order to replace that solution which are not so good in the nests. Definitely, cuckoo search algorithm can be implemented for the more complex case where every single nest has multiple no. of eggs which represent a set of solutions. For this task, we use the simplest approach where there is only one egg in each nest. In this case, no distinction is there between egg, nest or cuckoo [9].

Based on these three rules,
The basic steps of the Cuckoo Search which is Based on these three rules can be explained as the pseudo code given

```
begin
    Objective function f(x)
    Generate initial population of n host nest
    Evaluate fitness and rank eggs
    While (t > Max Generation) or stop
            criterion

        t = t +1
        Get a cuckoo randomly/ generate
        new solution by levy flights
        Evaluate quality/ fitness, F_i
        Choose a random nest j
        if ( F_i > F_j )
            Replace j by the new solution
        end if
        Worst nest is abandoned with
        probability P_a and new nest is built
        Evaluate fitness and rank the
        solution and find current best
    end while
    Post process results and visualization
end
```

When generating new solution $x^{(t+1)}$ denotes a cuckoo i, a levy flight is performed

$X_i^{(t+1)} = x_i^{(t)} + \alpha \bigoplus Levy(\lambda)$.

IV. Firefly Algorithm

Recently an new meta-heuristic inspired algirthm has been developed by Xin-She Yang in 2007 as Firefly Algorithm to solve the optimization problems. The flashing behavior of the firefly are molded into the mathematical formulation for solving problems with objective function related to flashing light or light intensity and their movement towards brighter one to obtain the optimum solution.

4.1 **Rules**: there are three ideal rules explained by the researcher:

1. All fireflies are unisex and they circulate towards the more attractive and brighter one irrespective of their sex.
2. The extent of the attraction of firefly is proportional to brightness which reduces with the increase into the distance between two fireflies seeing that air absorbs the light. If there is no brighter or more attractive firefly than a particular one, it will then flow randomly.
3. The brightness or light intensity is decided by the value of the objective function of a given problem and it's miles proportional to the light intensity for a maximization problem.

4.2 CHARACTERISTICS OF FIREFLY ALGORITHM

For designing the firefly algorithm few characteristics were considered in conciseness. They are the variance of the attractiveness and the light intensity [12-13].

4.2.1 Attractiveness: This characteristic describe a monotonically decreasing function in the Firefly and given by

$$\beta(r) = \beta_0^* \exp(-\gamma r^m), \text{ with } m \geq 1 \tag{10}$$

4.2.2 Distance: This equation describes the Cartesian distance between the two fireflies *i* and *j* at position y_i and y respectively:

$$r_{ij} = \left||y_i - y_j\right|| = \sqrt{\sum_{k=1}^{d} (y_{i,k} - y_{j,k})^2}, \tag{11}$$

Here, $y_{i,k}$ represents the k[th] component of the spatial coordination y_i for i[th] firefly and d represents the number of distance we have, for d=2, we have

$$r_{ij} = \sqrt{(y_i - y_j)^2 + (x_i - x)^2} \tag{12}$$

4.2.3 Movement: the movement of firefly i which is attracted through firefly j movement is given by the subsequent equation:

$$y_i = y + \beta_0 * exp(-\gamma r_{ij}^2) * (y_i - y_j) + \alpha * (rand - 0.5) \tag{13}$$

The first term defines the present location of a firefly and second term is firefly's attractiveness to light intensity seen by the adjoining firefly. Third term defines the random movement of a firefly if no brighter firefly is remaining.

Also, the coefficient α is a randomization parameter, and *rand* is a random value generator uniformly allotted in domain [0, 1]. Further, if $\gamma \to \infty$, the second term gets removed from the eq. no. (13) and the firefly movement turns into a random walk.

V. Harmony Search Algorithm

A new metaheuristic harmony search algorithm (HSA) is based on the performance of the natural musical processes which occur when a musicians find the harmony state, such as during jazz operation. Jazz improvisation [14-17]. These factor tries to make a lovely musical pleasing a best harmony state as determined by a beautiful standard, just like the optimization process seeks to find the best solution (global optimum-minimum cost or maximum benefit or efficiency or maximum benefit) as determined by objective function. Each musical instrument pitch determines the aesthetic quality, similar to the objective function value which is defined by using the set of values assigned to each design variable. The sounds for better aesthetic quality can be bettered by means of practice after then values for improved objective function progress can be bettered with periodicity. Musical Performance and Optimization observation process are shown in Table 5.1

5.1 Steps for harmony search algorithm

Step 1: Initialize the objective function and parameters.
Step 2: Initialize the harmony memory.
Step 3: Update the harmony memory.
Step 4: Check the stopping criterion.

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COMPARISON FACTOR	PERFORMANCE PROCESS	OPTIMIZATION PROCESS
Best State	Fantastic Harmony	Global Optimum
Estimated by	Aesthetic Standard	Objective Function
Estimated with	Pitches of Instruments	Values of Variables
Process Unit	Each Practice	Each Iteration

Table 5.1 Comparison b/w Musical Performance and Optimization Process

5.1.1 Initialize the problem and algorithm parameters

In step 1, initialize the parameters and optimization problem. The discrete size optimization problem is specified as objective function f (x) . The number of discrete design variables (x_i) and the set of available discrete values D_i.

$$D_i = \{ x_i(1),\ x_i(2),\ k,\ x(k) \} \quad (14)$$

$$\text{Min} f(x) \quad (15)$$

$$\text{Subject to } x_i \in D_i \quad i=1, 2, 3, k , \quad (16)$$

N is the number of variables and k is the number of possible values for the variables.

The harmony search algorithm uses some randomly parameters like harmony memory considering rate (HMCR), harmony memory size (number of solution vectors, HMS), pitch adjusting rate (PAR) and termination criterion (maximum number of searches) which are generated and required to solve optimization problem. HMCR and PAR parameters are used for improving the solution vector (HMS).

VI. Problem Formulation

6.1 ELD with fossil fuel only

The objective of ELD problem with fossil fuel units can be given as:

$$F_T = F_1 + F_2 + \dots\dots\dots + F_N \quad (17)$$

The objective function can be also describe as given below, which is to be diminished for best choicest result of the generation cost of generating units in the network.

$$\text{Min } F_T = \sum_{i=1}^{N} F_i(P_{gi}) \quad (18)$$

Subjected to,

$$P_d + P_L = \sum_{i=1}^{N} P_{gi} \quad (19)$$

In above equ. P_d is overall load demand and P_L is the transmission losses. Also, transmission line constraints and generator constraints are consider as follow.

$$P_L > 0 \quad (20)$$

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad (21)$$

6.1.1 Solar and Wind Power Estimation:-

6.1.1.1 Hourly wind speed and wind power output modeling

For the estimation of the speed of wind, the well known weibull's probability density function [18][19] is used. The pdf v for any time interval can be defined as:

$$f_v(v) = k/c*(v/c)^{k-1}\exp[-(v/c)^k] \quad (22)$$

where $f_v(v)$ is the distribution probability of the speed of wind (v), k and c are the shape and the scale parameter respectively. These parameters were taken out by the standard and mean deviation as given:

$$k = (\sigma/Vm)^{-1.086} \quad (23)$$

$$c = \frac{Vm}{\sqrt{(1+\left(\frac{1}{k}\right))}} \quad (24)$$

and the pdf for wind power could be formulated as:

$$f_{pw}(P_w)=\begin{cases} \left(\frac{k\ v_i\ l}{c}\right)\left(\frac{(1+\rho l)v_i}{c}\right)^{k-1} \exp\left(-\left(\frac{(1+\rho l)v_i}{c}\right)^k\right) & \text{for } v<v_r \\ 1-\exp\left[-\left(\frac{v_r}{c}\right)^k\right] + \exp\left[-\left(\frac{v_0}{c}\right)^k\right] & \text{for } v=0 \\ \exp\left[-\left(\frac{v_r}{c}\right)^k\right] - \exp\left[-\left(\frac{v_0}{c}\right)^k\right] & \text{for } v=v_r \end{cases} \quad (25)$$

Now the generated power of wind turbine at different velocities is calculated as:

$$P_w \begin{cases} 0 & \text{for } v_0 < v < v_i \\ P_{wt}\left(\frac{v - v_i}{v_r - v_i}\right) & \text{for } v_i \le v \le v_r \\ P_{wr} & \text{for } v_r \le v \le v_0 \end{cases}$$

(26)

where the $\rho = {}^{v}/_{v_r}$ and $l = {}^{(v_r - v_i)}/_{v_i}$, and v_r, v_i, v_0 are the rated , cut in and the cut out speed for WECS system.

6.1.1.2 Hourly solar irradiance and PV output modeling

Here, only considering the clearness index (k_t) pdf [19] to calculate the hourly sun irradiance and defined as the ratio of the horizontal global irradiance I_t (kW/m^2) to the extraterrestrial solar irradiance I_0 (kW/m^2). which can be calculated as:

$$k_t = \frac{I_t}{I_0}$$

(27)

$$f_{kt}(k_t) = c\left(1 - \left(\frac{k_t}{k_{tu}}\right)\right)\exp(\lambda kt)$$

(28)

Where λ and c are the mean value of clearness index and maximum value of clearness index, and were calculated as,

$$C = \lambda^2 k_{tu} / (\exp(\lambda k_{tu}) - 1 - \lambda k_{tu} \tag{29}$$

$$\lambda = \frac{(2\gamma - 17.519)\exp(1.3118\gamma) - 1062\exp(-5.0426\gamma)}{(k_{tu})} \tag{30}$$

$$\gamma = \frac{k_{tu}}{k_{tu} - k_{tm}} \tag{31}$$

in above equation, λ is decides the corresponding value of c and can be calculated from eq. 27. Further, the solar irradiance can be calculated as ,

$$I_\beta = [Tk_t - T'k_t^2] \tag{32}$$

$$T = \left[\left(R_b + \rho\frac{1 - \cos\beta}{2}\right) + \left(\frac{1 + \cos\beta}{2} - R_b\right)p\right]I_0 \tag{33}$$

$$T' = \left(\frac{1 + \cos\beta}{2} - R_b\right)qI_0 \tag{34}$$

where β known as inclination angel, R_b is define as the ratio of the beam radiation on a slant surface to the horizontal surface, while ρ is the reflectance of the ground. Also, p and q are the constants.

$$k = p - qk_t \tag{35}$$

Now from the above equation (30), T and T` will decide the pdf for solar power [20] providing the four conditions, but only two of them have physical significance as:
if T > 0 and T' < 0;

$$f_{pv}(P_{pv}) = \left\{\frac{c(k_{tu} - 0.5(\alpha + \alpha'))}{k_{tu}A_c\eta T'\alpha'}\exp\left(\frac{\lambda(\alpha + \alpha')}{2}\right)\right. \tag{36}$$

if T > 0 and T' > 0 then ,

$$f_{pv}(P_{pv}) = \left\{\frac{c(k_{tu} - 0.5(\alpha - \alpha'))}{k_{tu}A_c\eta T'\alpha'}\exp\left(\frac{\lambda(\alpha - \alpha')}{2}\right)\right. \tag{37}$$

where, the α and α' are given by,

$$\alpha = \frac{T}{T'}$$

and

$$\alpha' = -\sqrt{\alpha^2 - \frac{4P_{pv}}{\eta T' A_c}}$$

(38)

6.2 Objective Function for ELD with Renewable sources

Now, the modified objective function for ELD [20] with the renewable sources can be described as,

$$\text{minimize } F_t = \sum_{i=1}^{N} OC(P_{gi}) + \sum_{j=1}^{M} OC(P_{wj}) + \sum_{k=1}^{S} OC(P_{pvk}) \tag{39}$$

$$P_D + P_L - \sum_{i=1}^{N} P_{gi} - \sum_{j=1}^{M} P_{wj} - \sum_{k=1}^{S} P_{pvk} = 0 \tag{40a}$$

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \tag{40b}$$

$$0 \le P_{wj} \le P_{wrj}^{max} \tag{40c}$$

$$0 \le P_{pvk} \le P_{pvrk}^{max} \tag{40d}$$

The first term of the eq. 35 is the operating cost of the thermal units $OC(P_{gi})$, second term is the operating cost of the wind farms $OC(P_{wj})$ and the last term is the operating cost of the PV system $OC(P_{pvk})$ which is having P_{gi}^{min} and P_{gi}^{max} are the minimum and maximum limits of the i^{th} thermal generator units, P_{wj} and P_{wrj} are the scheduled

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power and rated power generation of the j[th] wind farms, similarly P_{pvk} and P_{pvrk} are the scheduled and the rated power generation of the k[th] solar unit.[20-21].

The wind farm operating cost is equal to the summation of three components, where first component is the weighted price characteristic that's primarily based on the rate of the wind, whereas the second part is penalty cost for no longer using the available power of wind and in final, the third part is the penalty value on the reserves which comes because of the real wind power is much lower than scheduled wind energy. the mixture of the running expenses may be defined as,

$$\sum OC(Pwj) = \sum_{j=1}^{M} C_{wj}(P_{wj}) + \sum_{j=1}^{M} C_{p,wj}(P_{wj,av} - P_{wj}) + \sum_{j=1}^{M} C_{r,wj}(P_{wj} - P_{wj,av}) \quad (41)$$

where,

$$C_{wj}(P_{wj}) = c_{wj} f_{pw}(P_w) P_{wj} \quad (42)$$

$$C_{p,wj}(P_{wj,av} - P_{wj}) = k_{p,wj}(P_{wj,av} - P_{wj}) \quad (43)$$

$$C_{r,wj}(P_{wj} - P_{wj,av}) = k_{r,wj}(P_{wj} - P_{wj,av}) \quad (44)$$

C_{wj} is the direct cost coefficient of jth wind unit, $k_{p,wj}$ and $k_{r,wj}$ are the penalty value coefficients for underestimation and reserve cost coefficient for overestimation of the to be had wind electricity and P_(wj,av) is the available wind power for the jth unit.

Similar to this, the sun farm operating cost is described, the sum of the three components: first part is the weighted value feature that's based at the sun irradiance, whereas the second part is the penalty value which are not using all of the to be had pv generated electricity and in remaining, the third part being the penalty value on the reserves which comes because of the actual sun electricity is much less than scheduled pv machine generated power. this mixture may be defined as,

$$\sum OC(P_{pvk}) = \sum_{k=1}^{S} C_{pvk}(P_{pvk}) + \sum_{k=1}^{S} C_{p,pvk}(P_{pvk,av} - P_{pvk}) + \sum_{k=1}^{S} C_{r,pvk}(P_{pvk} - P_{pvk,av}) \quad (45)$$

where,

$$C_{pvk}(P_{pvk}) = c_{pvk} f_{pvk}(P_{pv}) P_{pvk} \quad (46)$$

$$C_{p,pvk}(P_{pvk,av} - P_{pvk}) = k_{p,pvk}(P_{pvk,av} - P_{pvk}) \quad (47)$$

$$C_{r,pvk}(P_{pvk} - P_{pvk,av}) = k_{r,pvk}(P_{pvk} - P_{pvk,av}) \quad (48)$$

Above parameters defined as same as wind. In this problem we are consider that renewable power generators are situated near the load so that we can neglect the transmission losses.

VII. Result and Discussion

ELD problem with and without inclusion of renewable sources of power will be exercised on the four test cases and results will discussed and compared in this chapter with respect to fuel cost, transmission losses and elapsed time. The four test cases are as follows :-

7.1. CASE STUDY-1: THREE THERMAL UNITS SYSTEM

Here we are considered three thermal units and having different characteristics of cost function which is given below in following equations,

$$F1 = 0.00816\, P_{g1}^2 + 7.02P_{g1} + 200 \quad Rs/hr$$
$$F2 = 0.00900P_{g2}^2 + 6.35P_{g2} + 180 \quad Rs/hr$$
$$F3 = 0.00782\, P_{g3}^2 + 6.97P_{g3} + 140 \quad Rs/hr$$

For each generator unit, the operating limits are different which is shown below:

$$10\,MW \le P_1 \le 85\,MW$$
$$10\,MW \le P_2 \le 80\,MW$$
$$10\,MW \le P_3 \le 70\,MW$$

The transmission losses are calculated by knowing the loss coefficients which are taken from [39].

$$B_{ij} = \begin{matrix} 0.000218 & 0.000093 & 0.000028 \\ 0.000093 & 0.000228 & 0.000017 \\ 0.000028 & 0.000017 & 0.000179 \end{matrix}$$

$$B_{0i} = 0.0003 \quad 0.0031 \quad 0.0015$$

And $B_{00} = 0.030523$

From the results shown in table and graph, we can found that the fuel cost for three thermal units obtained from the cuckoo search technique is minimum among the rest two optimization techniques, viz. firefly algorithm and harmony search algorithm.

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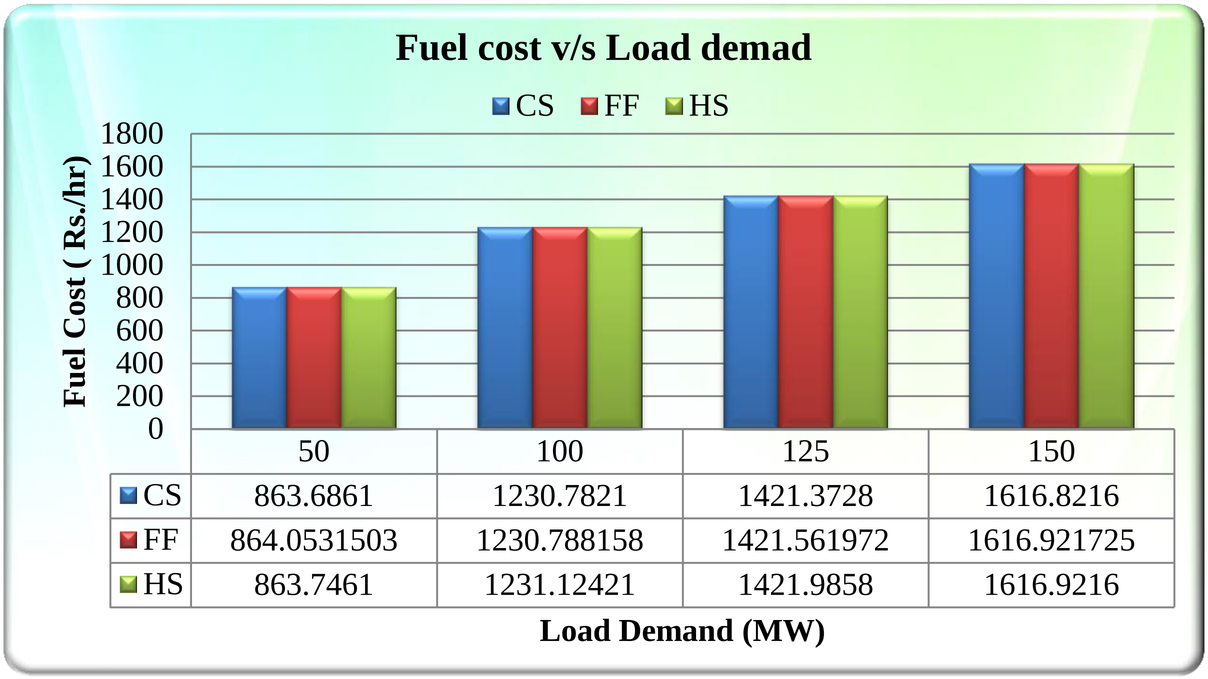

Figure7.1: **Fuel cost v/s load demand curve for case study 1**

Sr. No.	Load Dem-and	Fuel Cost			Transmission losses			Elapsed time		
		CS	**FF**	**HS**	**CS**	**FF**	**HS**	**CS**	**FF**	**HS**
1	50	**863.686**	864.0532	863.7461	**0.1124**	0.41735	0.1852	**0.72753**	2.7068	0.13582
2	100	**1230.78**	1230.788	1231.124	**0.2058**	1.34937	0.3319	**0.74232**	1.4268	0.13501
3	125	**1421.37**	1421.562	1421.985	**0.2449**	1.96477	1.2756	**0.75985**	2.0084	0.14291
4	150	**1616.82**	1616.922	1616.921	**0.2899**	2.72176	2.656	**0.73304**	2.3605	0.13312

7.2 Case Study-2: ELD with 3 Thermal Units and 2 Wind Units.

In this study, three thermal units taken with same fuel cost function and generator constraints for thermal units along side the two wind units. The running cost for the wind farm is shown in the equation 17, the coefficient direct cost for wind power is 4.89Rs/KWh, penalty cost coefficient is 17.280 Rs/KWh and coefficient reserve cost for the wind power is 4.89Rs/KWh. Each Wind unit has capacity of 30 MW. The all result with the various load demand are given in the Table 7.2 The cut in speed for wind turbine is 3.5 m/s, cut out speed is 25 m/s and the wind turbine rated speed units is 15 m/s. The notations of the variety of other parameters are given in appendix A. The fuel cost curve v/s load demand is shown in table 7.2. and fig7.2 respectively.

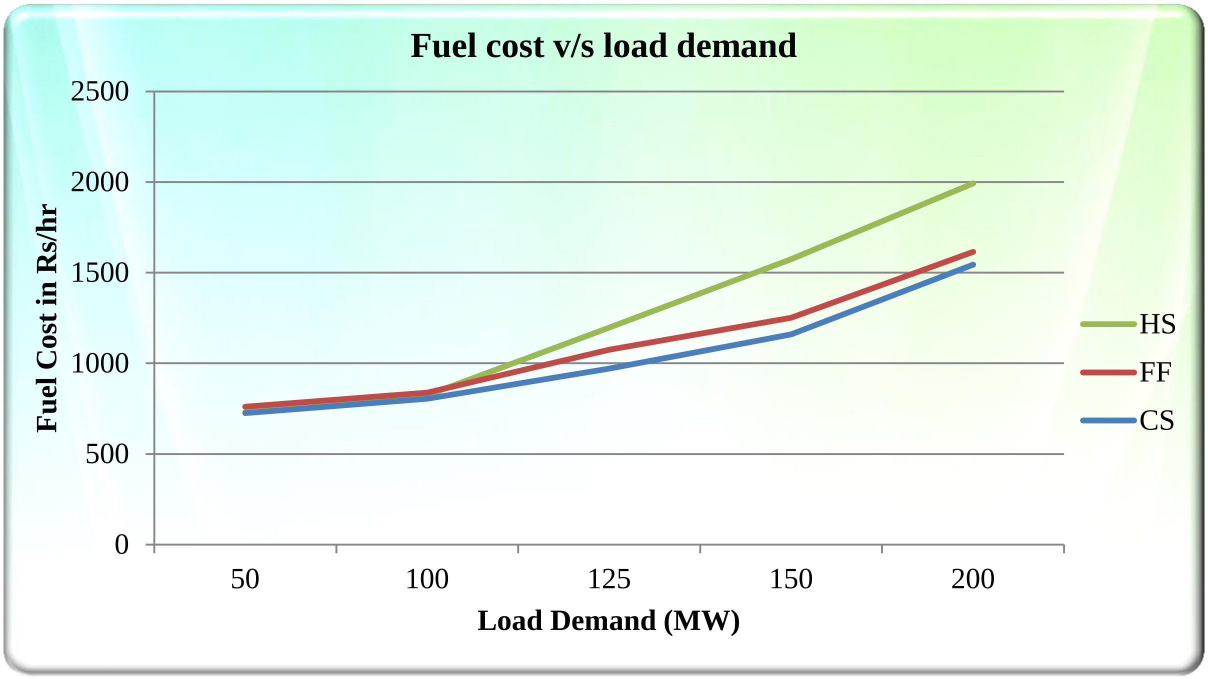

Figure7.2: Fuel cost v/s load demand curve for case study 2

Sr. No.	Load Demand	Fuel Cost			Transmission losses			Elapsed time		
		CS	FF	HS	CS	FF	HS	CS	FF	HS
1	50	725.929	760.909	730.33	0.1697	0.4856	0.1909	0.46797	2.0826	0.14358
2	100	805.4651	837.688	823.93	0.2875	0.8027	0.3313	0.45401	2.1376	0.13893
3	125	971.3191	1074.041	1195.79	0.6619	0.1406	1.2767	0.45931	1.1784	0.13221
4	150	1159.2875	1252.031	1573.51	1.2838	1.6745	2.6607	0.45733	1.2382	0.13624
5	200	1543.6336	1615.812	1993.64	2.4748	3.0919	4.5379	0.45948	2.2737	0.13512

Table 7.2.Results for ELD with three thermal units and 2 wind farm units

7.3. CASE STUDY-3: ELD WITH 3 THERMAL UNITS AND 2 PV UNITS.

There are 3 thermal units considered with same fuel cost function and generator constraints for thermal units alongside the two photo voltaic units. The coefficient of direct cost , penalty cost and reserve cost for the PV are 4.89Rs/KW, 17.280 Rs/KWh and 12.280 Rs/KWh respectively. Both PV unit has capacity of 30 MW. The result for the different values of load demand is shown in the Table 7.3 The cut out , cut in and the rated speed of the wind turbine units are 15 m/s, 25 m/s and 3.5 m/s respectively. The notations of the variety of other parameters are given in appendix A. The fuel cost curve v/s load demand are shown in table 7.3. and figure 7.3 respectively.

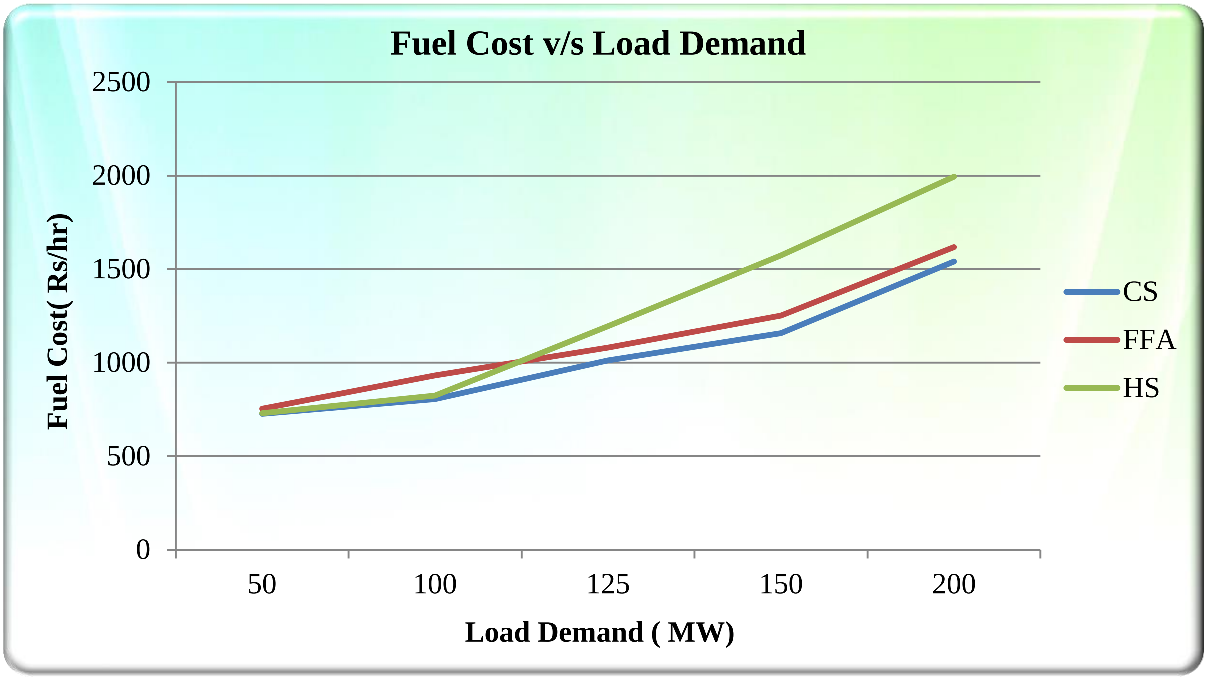

Figure7.3: Fuel cost v/s load demand curve for case study 3

Sr. No.	Load Demand	Fuel Cost			Transmission losses			Elapsed time		
		CS	FF	HS	CS	FF	HS	CS	FF	HS
1	50	**725.938**	753.8376	730.33	**0.1698**	0.2049	0.1893	**0.9366**	2.3812	0.1453
2	100	**805.581**	931.8645	823.93	**0.3109**	0.5110	0.3439	**0.8686**	1.4095	0.1360
3	125	**1012.724**	1081.215	1195.79	**0.7009**	0.8664	1.2459	**0.8978**	1.4156	0.1304
4	150	**1156.764**	1251.412	1573..51	**1.1386**	1.3965	2.6719	**0.8559**	1.6677	0.1343
5	200	**1540.419**	1618.327	1993.64	**1.9993**	2.7797	4.5201	**0.8031**	2.3801	0.1369

Table 7.3. Results for ELD with three thermal units and 2 photovoltaic units

7.4 CASE STUDY-4: ELD WITH 3 THERMAL UNITS AND 1 PV UNIT AND 1 WIND FARM UNIT.

Each unit has the capacity of 30 MW belonging to both PV and wind farm unit. The coefficient of direct cost, penalty cost and the reserve cost for wind and solar are not change it means same as in cases 2 and case 3. in the parameter In this case study , both cases study 2 and 3 are combined by us which is already discussed in the earlier section, but here we are going to do some changes, here we took one unit and values of the solar and wind units. The result is shown below in the Table 7.4 at different load demands. Also, the fuel cost for different load demands is shown in figure 7.4.

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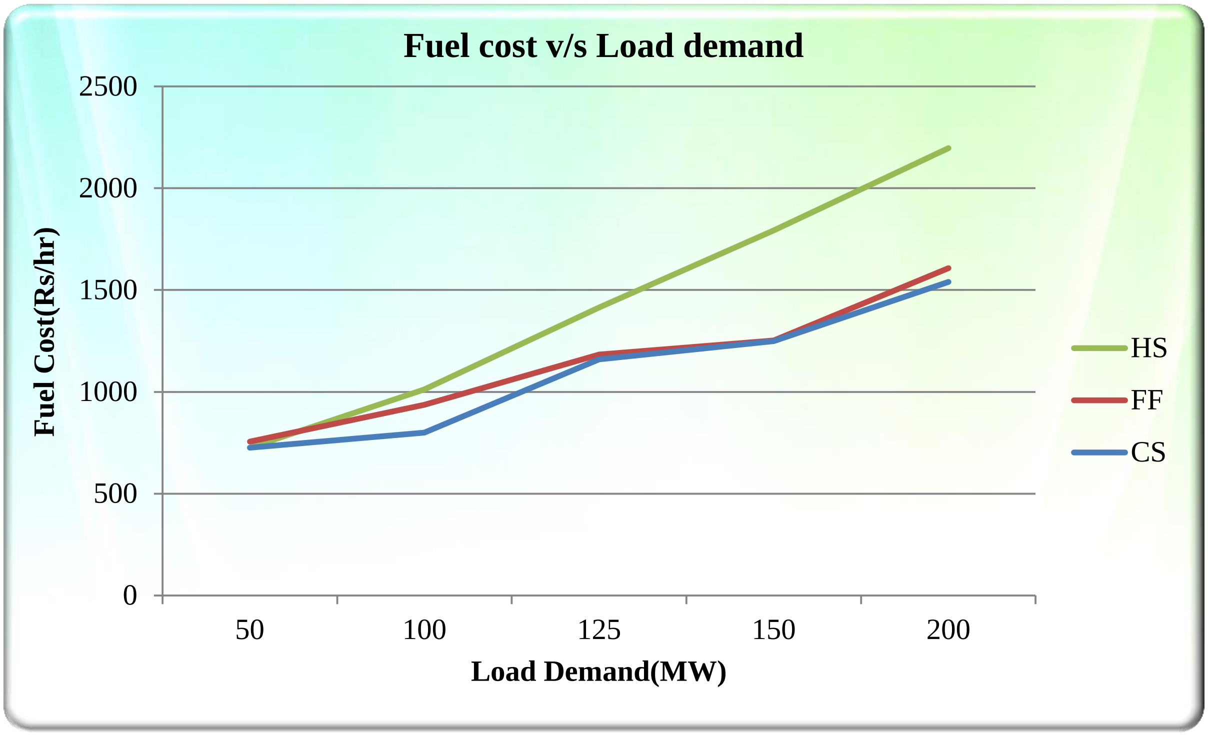

Figure7.4: Fuel cost v/s load demand curve for case study 4

Sr. No.	Load Demand	Fuel Cost			Transmission losses			Elapsed time		
		CS	FF	HS	CS	FF	HS	CS	FF	HS
1	50	**726.5127**	755.937	726.7415	**0.1715**	0.2096	0.1803	**05519**	2.6638	0.2365
2	100	**799.8708**	936.816	1011.41	**0.2796**	0.52384	0.7903	**0.5521**	2.4286	0.1735
3	125	**1160.322**	1118.31	1414.62	**1.1663**	0.89685	1.9651	**0.5840**	1.5697	0.1732
4	150	**1248.509**	1252.76	1793.91	**2.4390**	1.44612	3.6237	**0.57564**	1.3889	0.1749
5	200	**1540.407**	1607.55	2196.5	**2.4492**	2.79848	5.9471	**0.5655**	1.3924	0.1764

Table 7.4. results for ELD with three thermal units and 1 PV units and 1 wind farm unit

VIII. Conclusions

In the paper, various test cases were implemented with the different load demands, when we include the renewable energy sources and simulate the dispatching of load demand. It is found that both the transmission loss and the fuel cost of the thermal generating units are reduces to higher extent. Also show that cuckoo search algorithm gives better result than harmony algorithm and firefly techniques The transmission loss due to the power transfer from renewable farms to load center is assumed to be negligible, since their location is near to the load. This phenomenon become success when the load demand shared by the renewable sources with thermal units. The fuel cost reduces with keeping the energy balance and other constraints within limits. A proper formulated probability density functions for solar and wind are used to find the actual probability of wind, solar power and evaluated for that location where we can estimate wind and solar power. The entire test were performed on the MATLAB R2015b.

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