Emission Minimization with Artificial Bee Colony Algorithm Incorporating Distributed Generation Sources

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Abstract: ***This paper presents fuel cost and an emission minimization economic dispatch problem to examine effects Distributed generation sources like wind power and solar power on emission control in thermal power plant. The unsystematic nature of wind power is characterized by weibull probability distribution function to solve the probabilistic wind thermal economic emission dispatch problem. Maximum and minimum of wind power and an irradiance of solar power data for a particular day in each season can be described as a bimodal distribution function are considered in this work. A powerful method Artificial Bee Colony (ABC) algorithm is used to minimize the fuel cost and emission function and implemented in Matlab program. The effectiveness of ABC algorithm is verified by the result found on Standard IEEE six thermal units, and 30 bus systems. The optimized generation allocation, fuel cost, and emission reduction is obtained from proposed algorithm. For validating the effectiveness of ABC algorithm an economic emission dispatch problem is solved with and without considering wind and solar power. Finally results are comparing with particle swarm optimization (PSO) technique; from the result of comparison found that ABC method is more superior.***

Keywords: ***emission, wind, solar, ABC, PSO, weibull probability distribution function***.

1. Introduction

India remains the 5th largest consumer of electricity in the world. All India total installed capacity is 237742.94MW out of that from coal fired plants are generating 140723.30MW. Coal is the primary fuel for electricity generation in countries like India, China and across world, the coal and nuclear usage is continuously increasing to meet the energy demands of the country. Nuclear power plants will produce less emission but disposal of ash content and cost of the fuel are the main issues. Therefore, coal fired power plant occupies more than 65 percent of the power demand [10]. Indian coal contains a high ash content of around 30-40 percent with average calorific value of 4000 kcal/kg and average sulphur content of 0.35 percent [4]. Power generation projects require not only huge capital investment but also various natural resources like, fossil fuels and water, suitable site, transportation and engineering technology. Thus make considerable impacts on the environment and generate remarkable stress in the local eco-system [6]. Due to burning of coal produce green house gases like Carbon dioxide (CO_2), Sulphur dioxide (SO_2) and Nitrogen oxide (NO_x) that creates global warming.

Electrical power systems are designed and operated to meet variation of power demand. In power system, minimize the operation cost is very important. Economic load dispatch (ELD) is a method to schedule the power generator output with respect to the load demands, and to operate the power system most economically, or in other words, the main objective of economic load dispatch is to allocate the optimal power generation from different units at the lowest cost possible, while meeting all system constraints. As per regulation of government on environmental protection, the energy availability with minimum fuel cost cannot be the only basis of electrical power dispatch. But there is a requirement from social is adequate and secure electrical energy with minimum levels of pollution and cheaper in price.

There are several methods are available for reducing emission like switching low sulphur content coal, Pre and post cleaning system, etc.., but those approaches are costlier therefore combined economic emission dispatch with artificial bee colony algorithm by incorporating renewable sources like wind, solar power reduces considerable amount in fuel cost, transmission losses and an emission with considering all system constraints [2].

2. Indian Coal

2.1Coal resources

The Ministry of Coal effectively finds out all matters that are relating to the production, storage, supply, distribution and sale price of coal. India has an estimated 22,400 square kilometres (sq. km) of potential coal bearing area. Most of the major coal deposits are Gondwana coals in the eastern and south eastern parts of India; the Tertiary coals are located in Assam and other north eastern states, as well as Jammu and Kashmir. Indian coal is primarily bituminous and sub bituminous; there are nearly 36 gigatons (GT) of lignite resources in Tamil Nadu, Gujarat, Rajasthan, Jammu and Kashmir [11].

2.2 Classification of coal

Coal is classified into three major types' viz., lignite, bituminous and anthracite. However there is no clear differentiation between them and further we can classified coal as semi-anthracite, semi-bituminous, and sub-bituminous. Anthracite is the oldest coal from geological perspective having higher calorific value. It is in the form of hard with lower volatile contents and negligible amount of moisture contents. Lignite is the youngest coal from geological perspective. It is in the form of soft and mainly contains volatile matter and moisture content with low fixed carbon. Classification of coal on the basis of calorific value is shown in the table normally D, E and F coal grades are available to Indian Industry.

Table 1: The gradation of Indian coal based on its calorific value

Grade	*Calorific Value Range (in kCal/kg)*
A	Exceeding 6200
B	5600-6200
C	4940-5600
D	4200-4940
E	3360-4200
F	2400-3360
G	1300-2400

3. Mathematical Formulation

3.1 Non Linear Cost Function

The thermal power plants employed for electricity generation consist of generating units having multiple valve steam turbines. The generating units with multi-valve turbines have very non-linear cost function, C (P) as given below:

$$C(P) = \sum_{i}^{n} (a_i + b_i P_i + c_i P_i^2) + (e_i \sin f_i (P_{i,min} - P_i)) \quad (1)$$

Where, a_i, b_i, c_i, e_i, f_i are fuel cost coefficients of i^{th} unit. P_i Represents active power output and P_{imin} represents minimum power output of i^{th} thermal unit in MW.

3.2 Emission Function

The emission, E produced by each generating unit can be approximated as a quadratic function. The emission function is given by.

$$E(P) = \sum_{i}^{n} (\alpha_i + \beta_i P_i + \gamma_i P_i^2) \quad (2)$$

Where, α_i, β_i, γ_i represents fuel cost coefficients of unit.

3.3. Direct cost function for wind and solar power

In this paper all wind turbines in the wind-farm are represented by single wind turbine. Similarly all solar panels in solar-plant are considered as a single Photo voltaic panel. A linear cost function for power output of i^{th} wind farm and j^{th} PV plant is formulated as follows.

$$C_t = d_i W_i + d_j P_{sy} \quad (3)$$

Where, d_i is the direct cost coefficient for the i^{th} wind farm and d_j is the direct cost coefficient for the i^{th} PV plant.

3.4 Emission Minimization Model Considering Wind and solar power

The problem of emission minimization constrained by power demand is as follows.
Minimize, E (P) Subject to

$$\sum_{i}^{n} P_i + \sum_{i}^{k} W_i + \sum_{i}^{j} P_{sy} = P_D + P_L \quad (4)$$

$$C(P) + \sum_{i}^{N} C_w(W_i) + \sum_{i}^{N} C_s(P_{sy}) \le C_{max} \quad (5)$$

$P_{i,min} \le P_i \le P_{i,max}$;$0 \le W_i \le W_{r,i}$; $0 \le P_{sy} \le P_{sy,\ max}$

Where Wi is the scheduled wind power output of i^{th} wind farm in MW, Psy is power output from PV panel in MW, P_D is the system load demand in MW, P_L is the loss in power carrying lines in MW, n is the number of coal based units, k is the number wind farms, P_i represents active power output, $P_{i,min}$ is minimum allowable power limits of i^{th} generator in MW, $P_{i,max}$ is maximum allowable power limits of i^{th} generator in MW, Wr,i is rated power of wind farm, C(.) is cost of operation of i^{th} coal based unit, C_w (.) is cost of operation of i^{th} wind farm and Cs(.) is cost of operation of i^{th} PV Plant[1].

4. Wind and Solar power model

4.1 Wind Power Model

The wind speed variations for a given site can be well defined by the weibull pdf, $f_{(v)}(v)$ with two parameters, the scale parameter (*c*) and the shape parameter (λ) [1].

$$f_v(v) = \left(\frac{\lambda}{c}\right)\left(\frac{v}{c}\right)^{(\lambda-1)} e^{-(v/c)^{\lambda}}, \quad \#$$

$$0 < v < \infty \quad (6)$$

The cumulative distribution function (CDF) is represented by following equation,

$$f_v(v) = 1 - e^{-(v/c)^{\lambda}} \quad (7)$$

The power generated by the wind powered generators can be represented by following equation

$$W = \frac{1}{2}\rho A V^3 C_p \quad (8)$$

Where, ρ is the density of air, A is area swept by the wind turbine blade, V is wind speed, C_p is the performance coefficient.

The power generated by the wind turbine at different wind velocities is stated as,

$$w = 0, \qquad v < v_i > v_0$$

$$w = w_r \frac{(v - v_i)}{(v_r - v_i)}, \qquad v_i \le v \le v_r \tag{9}$$

$$w = w_r, \qquad v_r \le v \le v_0$$

Where, v_i, v_0 and v_r are cut-in, cut out and rated wind velocity for wind powered system respectively.

4.2 Output Power of a PV Module

The irradiance data for a particular day in each season can be described as a bimodal distribution function. The data are divided into two groups, each is described using a unimodal distribution function, and a Beta pdf is utilized as [5].

$$f_b(s) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} * s^{(\alpha+1)} * (1-s)^{(\beta-1)} \\ 0 & otherwise \end{cases} \tag{10}$$

Where, s is the solar irradiance (kW/m2), f_b (s) is the Beta distribution function of s and α, β are the parameters of the Beta distribution function. The output power of the PV module is dependent on the solar irradiance and ambient temperature of the site as well as the characteristics of the module itself. Therefore, once the Beta pdf per sitel is generated for a specific time segment, the output power during the different states is calculated for this segment using the following:

$$T_{C_y} = T_A + s_{ay}\left(\frac{N_{OT} - 20}{0.8}\right)$$

$$FF = \frac{V_{MPP} * I_{MPP}}{V_{OC} * I_{SC}} \tag{11}$$

$$I_y = s_{ay}\left[I_{SC} + K_i\left(T_{C_y} - 25\right)\right]$$

$$V_y = V_{OC} - K_v * T_{C_y}$$

$$P_{s_y}(s_{ay}) = N * FF * V_y * I_y$$

Where,
T_{Cy} is the cell temperature ◦C during state y,
T_A is the ambient temperature ◦C,
K_v is the voltage temperature coefficient V/◦C;
K_i is the current temperature coefficient A/◦C;
N_{OT} is the nominal operating temperature of cell in ◦C;
FF is the fill factor
I_{SC} is the short circuit current in A;
V_{OC} is the open-circuit voltage in V;
I_{MPP} is the current at maximum power point in A;
V_{MPP} is the voltage at maximum power point in V;
P_{sy} (s_{ay}) is the output power of the PV module during state y;
S_{ay} is the average solar irradiance of state y.

5. ABC algorithm

This model was introduced by Dervis Karaboga in 2005; ABC algorithm is based on the intelligent way of the bees interacting with each other. Honey bees being social insects divide their work among themselves, Employed bees, Onlooker bees and Scout Bees. Their activities are categorized into four main phases: Initialization phase, Employed bee phase, Onlooker bee phase and Scout bee phase. In initialization phase, each employed bee is assigned with different food resources. In employed bee phase, each employed bee calculates the nectar amount of the food resource associated with it and the distance of it from the hive. After collecting the important information of the source the employed bee share the gathered information with the bees waiting in the hive. In onlooker bee phase, onlooker bees (the bees waiting in the hive) read information regarding different food resources and choose the best food resource. In scout bee phase, the employed bees whose food resource becomes abandoned turns into scout bee. The main job of scout bees is to search for new food resources

5.1. The step by step procedure for proposed method

Step 1: Specify generator cost coefficients, emission coefficients, generation power limits for each unit and B-loss coefficients. Initialize the four control parameters of ABC algorithm and maximum cycle for termination process.

Step 2: Initialization of the ABC algorithm parameters.
In this step, the parameters of the ABC algorithm, such as the colony dimension, maximum cycle number (MCN), number of variables, and limit parameter, are initialized.

Step 3: Initialization of the population with a random solution.
In this step, a set of food sources (initial population of S solutions xi (i = 1, 2,......S)) is generated randomly by the bees and their nectar amounts are determined, where S corresponds to size of the employed bees. Each solution xi is represented by a D-dimensional vector, where D corresponds to the number of parameters to be optimized.

Step 4: Evaluation of the fitness.
In this step, evaluation of the fitness function of each food source position corresponding to the employed bee in the colony is done using the error following equation.

$$e_i = FC_{i(actual)} - FC_{i(estimated)} \tag{12}$$

Step 5: Modification of the food source position and local selection by the employed bee. In this step, an employed bee modifies the food source position, finds a new position (solution) using her visual information belonging to that source in her memory, and tests the nectar amount of the new source. In the ABC algorithm, the new food source found by the employed bee is described as follows:

$$v_{ij} = x_{ij} + \delta_{ij}(x_{ij} - x_{kj}),\ k(1,2,...S),\ (1,2,.....D), \tag{13}$$

where, k and j are randomly chosen indices and δ is a random number in the interval of [-1,1]. In fact, δ_{ij} gives a comparison between 2 sources found, the new and the old. After v_{ij} is produced and its fitness is evaluated, the comparison is done by the employed bees. According to the comparison, if the fitness value of the new food source is better than that of the old one, the new food source is kept in the memory and the old one is discarded; otherwise, the new

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one is discarded from the memory and the old one is kept. This selection is called local searching or greedy selection process in the ABC algorithm. In this process, if the new food source is selected instead of the old one, a limit count is set.

Step 6: Employ the onlookers for the selected sources and evaluate the fitness.

After completion of the local search process in Step 5 by the employed bees, they come back into the hive and share the nectar amount information of the sources with the onlooker bees waiting at the dancing area. In fact, these onlooker bees were called employed bees before going to the food source that they visited. In this step, onlooker bees make a new food source choice according to the information they took from the employed bees and the nectar amount is calculated. This process of choosing a food source depends on the probability value Pi associated with the fitness of that food source and is formulated as follows:

$$P_i = \frac{fit_i}{\sum_{j=1}^{s} fit_j} \qquad (14)$$

Where, t_i is the fitness value of the i^{th} solution and s is the total number of food sources.

Step 7: Modification of the food source position by the onlookers.

In this step, the onlookers modify the food source position to find a new position (solution) using the visual information belonging to that source in their memory and check the nectar amount of the new source, just as in the case of the employed bee in Step 5. The greedy selection process is done again for the onlookers in this step. That is, if the fitness value of the new food source is better than that of the old one, the new food source is kept in the memory and old one is discarded; otherwise, the new one is discarded from the memory and the old one is kept.

Step 8: Abandon the exploited food sources.

This step is done according to the `limit' parameter, which is a predetermined number of cycles for releasing the food source. In the ABC algorithm, a solution is abandoned when that solution can not improve further for the determined limit value. In this step, when the nectar amount is abandoned in this way, one of the employer bees is determined randomly as a scout bee to find a new food source. This process is described as follows:

$$x_i^j = x_{min}^j + \beta\left(x_{max}^j - x_{min}^j\right), \quad j \epsilon (1, 2, \dots D) \qquad (15)$$

Where, β is a random value in the interval of [0,1], and x^jmin and x^jmax are the minimum and maximum limits of the parameter to be optimized.

Step 9: Keep the position achieved so far and increase the counter of the cycle.

Step 10: Stopping of the global searching process.

In the ABC algorithm, steps 5 through 10 are repeated until the criterion is met. Next, this global searching process stops. The criterion is a predetermined cycle number called the MCN. The flow chart of the ABC algorithm is shown in Figure (1).

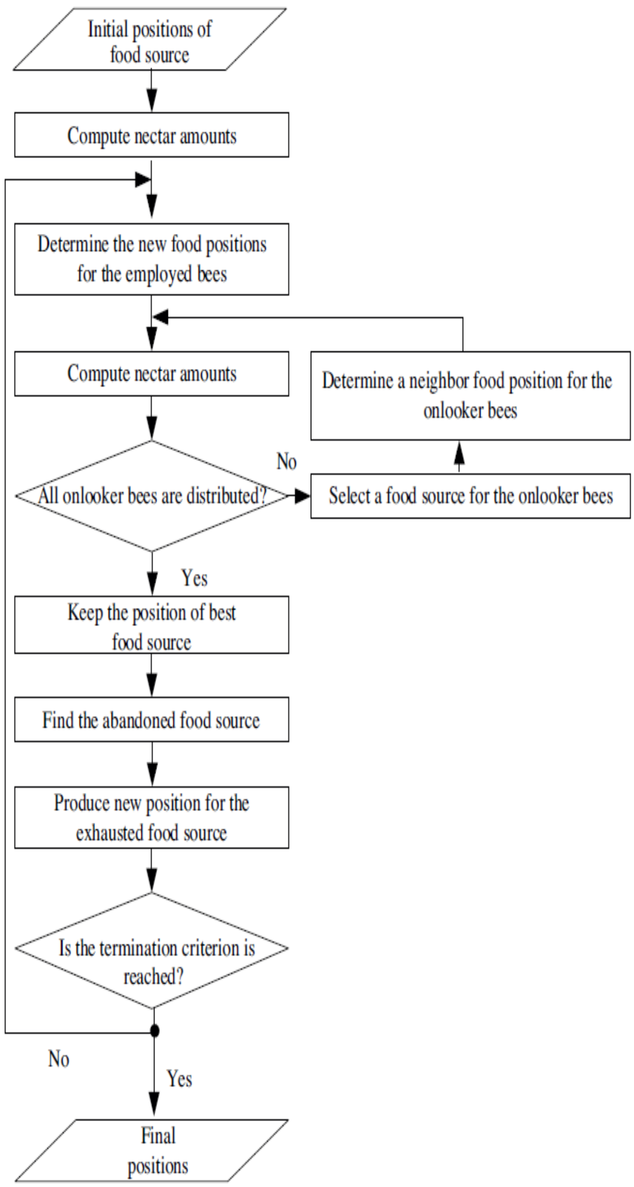

Figure 1: Flow chart of ABC algorithm

5.2 Application and Disadvantages of ABC

Exploration and exploitation both are important part of meta-heuristic optimization mechanisms to get best feasible solution from the whole search space. Exploitation is an ability of algorithm to produce better solution from old solution, while exploration implies the ability of search process to track to global optimum. In ABC, there is an equal probability of getting a good food source and a bad food source due to modification as the new food source is randomly generated. Here, ABC is good at exploration but not in terms of exploration. And this requires more computation time.

Large numbers of real-world optimization problems have been solved by the ABC algorithm that demonstrates the utilization and effectiveness of this algorithm. The areas of ABC application include Benchmark optimization, Bioinformatics field ,Data Mining, Engineering design and applications ,Scheduling.

6. Simulation Results

6.1 Generation Scheduling without DG Sources

To determine the effectiveness of the ABC algorithm six unit 30 bus systems is studied without considering Distributed generation sources. Figure 2 shows the 6 thermal generating units with 30 bus system, each generating unit have different generating limit.

The table 1; shows generating limits of units. table 2; shows fuel cost data of six unit, table 3; shows ramp rate limits of six unit [7].

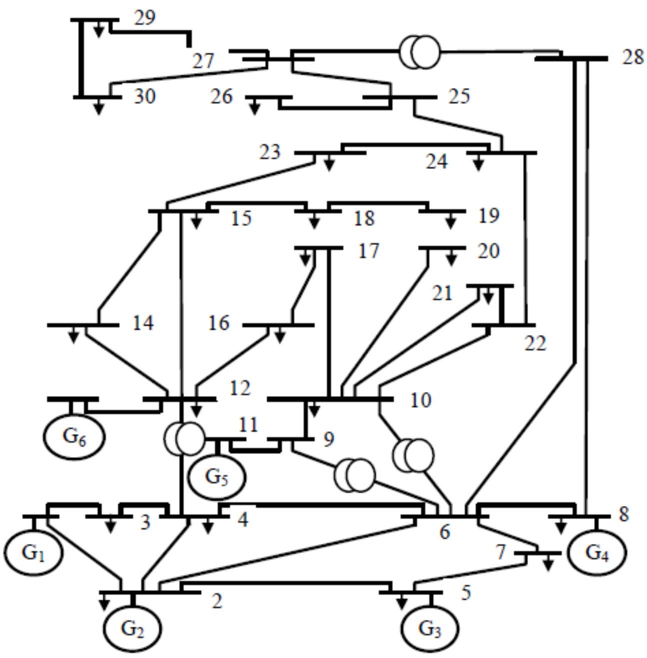

Figure 2: IEEE 6 unit 30 bus test system

Table 2: Maximum and Minimum limits of six units

Unit number	*Pi min (MW)*	*Pi max(MW)*
1	100	500
2	50	200
3	80	300
4	50	150
5	50	200
6	50	120

Table 3: Fuel cost data of six units system

UNITS	**ai ($)**	**bi ($/MW)**	**ci ($/MW²)**	**Pi min(MW)**	**Pi max(MW)**
1	240	7	0.007	100	500
2	200	10	0.0095	50	200
3	220	8.5	0.009	80	300
4	200	11	0.009	50	150
5	220	10.5	0.008	50	200
6	190	12	0.0075	50	120

Table 4: Ramp rate limits of six units system

UNITS	$P_i^0(MW)$	$UR_i(MW/h)$	$DR_i(MW/h)$
1	340	80	120
2	134	50	90
3	240	65	100
4	90	50	90
5	110	50	90
6	52	50	90

Table 5: Emission coefficients

Unit	α_i	β_i	γ_i	**Pi min(MW)**	**Pi max(MW)**
1	0.007	7	240	100	500
2	0.0095	10	200	50	200
3	0.009	8.5	220	80	300
4	0.009	10	200	50	150
5	0.008	10.5	200	50	200
6	0.0075	12	190	50	120

The transmission losses are calculated by B matrix loss formula which for 6-unit system is given as [7],

$$B_{ij} = 10^{-3}\begin{bmatrix} 1.7 & 1.2 & 0.7 & -0.1 & -0.5 & -2.0 \\ 1.2 & 1.4 & 0.9 & 0.1 & -0.6 & -0.1 \\ 0.7 & 0.9 & 3.1 & 0.0 & -1.0 & -0.6 \\ -0.1 & 0.1 & 0.0 & 0.24 & -0.6 & -.8 \\ -0.5 & -0.5 & -0.1 & -0.6 & 12.9 & -0.2 \\ -2.0 & -1.0 & -0.6 & -0.8 & -0.2 & 15.0 \end{bmatrix}$$

$$B_{0j} = 10^{-3}[0.398 \quad -1.297 \quad 7.047 \quad 0.591 \quad 2.161 \quad -6.635]$$

$$B_{00} = 0.056$$

6.2 Simulation Result for Normal Power system

Normal power system means only power generated by six thermal unit is considered, there is no distributed generation (DG) sources are incorporated. The results obtained is shown tables 6, where, PD- Power demand (MW), P1 to P6 power generated by the individual units. TG-Total generation (MW) is the sum of power generated by all six thermal units, Em- Emission (kg/hr), TL-Total transmission loss (MW), FC- Fuel cost ($/hr) respectively.

Table 6: Normal power system

Unit	*PSO Normal system*	*ABC Normal system*
P1	308.93	363.83
P2	199.99	118.77
P3	231.16	283.69
P4	149.99	140.21
P5	200	185.53
P6	120	119.72
TG(MW)	1210.07	1211.75
PD(MW)	1200	1200
TL (MW)	10.0647	9.16628
FC($/hr)	14746.6	14537.6
Em(kg/hr)	1337.36	1326.2

In table 6; two different solution techniques for solving economic emission dispatch problem are considered viz, PSO and ABC technique. In both cases load demands is taken as 1200MW and simulation results are noted in a table format.

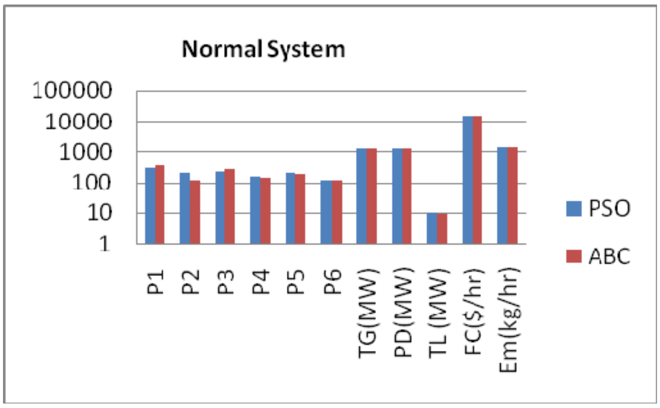

Figure 3: Plot PSO and ABC for Normal power system

From the above result it is concluded, the total power generation, Emission output, total transmission loss and fuel cost are gradually increases in both cases as the demand of power is increases. Finally the results are shows for same power demand; solutions obtained by the ABC algorithm are superior than PSO technique. The total power generation is more, emission output is less, total transmission losses are minimum and the cost of the fuel is low when comparing ABC with PSO for same power demand.

6.3. Simulation Result with Wind and Solar Power system

In this section wind and solar power are added with power generated by thermal unit, total power generated is the sum of thermal plus wind, plus solar. The power generated by wind and solar is depends on environmental factors. Due to easier of work power generated by wind and solar taken as constant value.

NOTE- In table 7; sum of power generated by all six thermal units plus wind and solar power (fixed value) is considered.
Wind Power =40.5571 MW
Solar power =0.221426 MW

Table 7: with wind Solar Power

Unit	Wind & Solar PSO	Wind & Solar ABC
P1	270.83	317.56
P2	200	154.27
P3	228.01	261.9
P4	149.99	145.21
P5	199.99	200
P6	120	110.51
TG(MW)	1168.82	1189.45
PD(MW)	1200	1200
TL (MW)	9.59665	8.59279
FC($/hr)	14185.5	14010.6
Em(kg/hr)	1113	1083.9

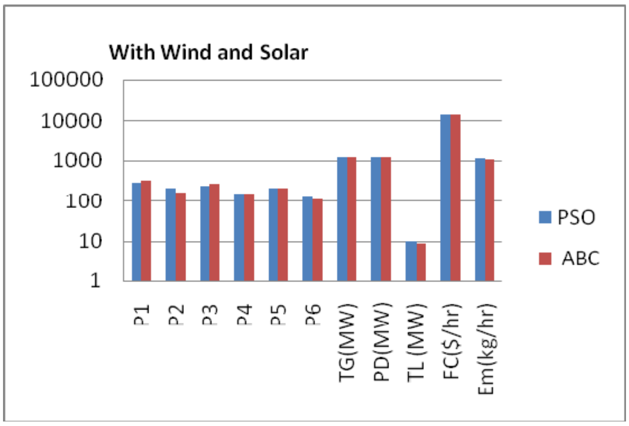

Figure 4: Plot PSO and ABC for with wind and solar power

The above figure 4; shows a plot of power system when considering wind & solar power. Here wind and solar power is taken are taken constant, power demand is 1200 MW, Emission value is 1083 (kg/hr).

7. Conclusion

Environmental concern is an extremely important issue in the operation of present day power systems. The various classes of coal contain deferent levels of emission, an artificial bee colony algorithm for combined economic and emission dispatch has been proposed in this work. The conventional technique of economic thermal power dispatch method is complex and does not provide exact result and emission value is more that affects on environment constraints.

The proposed technique ABC algorithm by incorporating wind and solar power is reduces a considerable amount fuel cost, transmission loss and in emission output value. The results are tested on standard IEEE six thermal unit and 30 bus data. In this work two different fixed values of power demand is considered, but in practically it various randomly.

In this work two cases are taken in first case normal thermal power system without considering wind and solar power and next case is considering by wind solar power. Both above said two situations are tested by PSO and ABC solution technique by varying power demand. The proposed technique is compared with PSO method economic/emission dispatch. By the result it is concluded ABC method is more superior.

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