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Reduction of Carbon Dioxide Emission in Thermal Power Plants using Fire Fly Optimization Technique

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ABSTRACT

Global Warming is the greatest challenge that the world is facing today. It is very important to take preventive measures before this problem poses a serious threat to the mankind. Power Plants play a major role in green house gas emissions. Nearly 21.3% of green house gases are emitted by these power plants alone. In this paper we try to propose a computational approach to reduce these carbon dioxide emissions by using Fire Fly Optimization Technique. The proposed optimization technique is better than other conventional optimization techniques in terms of computational time and number of iterations. It also shows that the method is practically applicable in real time. The technique was applied to a three generator and six generator systems for different load demands for validation. To check the quality of the solution the results are being compared with the conventional optimization algorithms.

Keywords

Fire Fly Optimization Algorithm, Carbon dioxide emission, Green House Gases, Thermal Power Plant, Fossil Fuels.

1. INTRODUCTION

Electricity has become one of the basic needs of the world. Presently there is already a huge demand for power and with the emergence of new industries and the increase of consumers of electricity; this demand is expected to grow even more in the next two decades. Even though non-conventional sources of energy like hydel and nuclear are being involved, still the major share of the power is contributed by thermal power plants only as the reliability and safety factor is higher and thermal power plants are suited for base load demands.

The rising concentrations of green house gases (GHGs) of anthropogenic origin in the atmosphere such as Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O) have increased, since the late 19th century. According to the Third Assessment Report (TAR) of the inter government Panel on climatic changes, because of increase in the concentration of the green house gases in the atmosphere in the last 100 years, the mean surface temperature has risen by 0.4-0.8^{0}C globally. The precipitation has become spatially variable and the intensity and frequency of extreme events has increased. The sea level has also risen at an average rate of 1-2 mm during this period. This continuous increase in the concentration of the green house gases will result in more severe changes in the eco system and may cause imbalance in the nature. In this industrial era, many activities of the man emit the green house gases into the atmosphere, mainly through burning fossil fuels and deforestation. The carbon dioxide emissions by burning of fossil fuels can be classified into seven categories namely, Solid fuels 35%, liquid fuels 36%, gaseous fuels 20%, flaring gas <1%, cement production 3%, non-fuel hydrocarbons <1%, the international bunkers of shipping and air transport 4%. To minimize these emission researchers have proposed solutions that use the artificial intelligence techniques.

Recent advancements in computational intelligence, especially in the area of evolutionary computing, made scientists realize that nature is a great inspiration to design techniques which are used in development of intelligent systems and algorithms. Researchers started to concentrate on the nature inspired algorithms which mimic the natural phenomenon to develop intelligent algorithms. Some of the nature inspired algorithms include the Genetic Algorithm (GA), Artificial Bee Colony Algorithm (ABC), Monkey Search Algorithm (MS), Bacterial Foraging, Big Bang Big Crunch Algorithm (BBBC), Fire Fly Algorithm. These algorithms proved to be worth in solving many problems in engineering. Some of the areas where these nature inspired algorithms have been phenomenal include Economic Load Dispatch (ELD) Problem, Unit Commitment (UC) Problem in power systems, Tuning control gains of a controller in a process in Control Engineering.

Fire flies also called as Lighting Bugs are one of the nature's fascinating creatures. These flies are capable of producing light using their special photogenic organs situated very close to their body surface. They use these light emitting capability for various reasons like social behaviour, prey attraction, warning signal when a predator arrives, organizational behaviour and many more. Lot of research is being done on these fire flies in bio-chemical as well as engineering for various reasons. As researchers succeeded in finding solutions to many optimization problems by mimicking many naturally inspired patterns like Ant Colony Optimization, Artificial Bees Colony Optimization, Monkey Search Optimization etc,. They succeeded in applying the Fire Fly behaviour to optimization problems hence getting some good results.

In this paper we attempt to apply the Fire Fly Optimization Algorithm to reduce the carbon dioxide emission from thermal power stations. Rest of the paper is organized as follows: section2 we discuss about global warming, problem formulation in section 3, Fire fly Algorithm in section 4 and results & evaluation in section 5.

2. GLOBAL WARMING

The fuel used in thermal power plants are fossil fuels and the majorly used fossil fuel is coal. Use of fossil fuels in thermal power plants gives rise to two serious environmental concerns: one being the possible exhaustion of coal and other which is even more significant is Global Warming.

Global warming is the increase in surface and sub-surface temperatures across the earth. This phenomenon leads to a situation where the global balance between various eco-systems is disturbed. It has been calculated that the average temperatures have risen by around 0.75 ^{0}C with an uncertainty factor because the response of all biospheres on earth towards global warming is not the same. The Tundra or polar ice caps are melting as a result and has led to increase in ocean levels.

The relation between thermal power plants and the Global warming is explained by another concept called Green house effect. Certain gases like carbon dioxide and water vapor capture the heat radiated by the earth's surface back to the atmosphere and lead to what is called warming. This phenomenon by which the gases are not allowing infra-red radiations from the surface to leave the atmosphere is called Green-house effect and the gases are called Green-house gases. The major Green-house gas is CO_2. The carbon dioxide content in the atmosphere has seen a rapid increase since 1880 since the beginning of the Industrial revolution .The major contributors to CO_2 in the atmosphere are due to human activities and are emissions from power plants. Nature has its own way to counter this increase. The CO_2 in the atmosphere is used in the photosynthesis process by plants and carbon dioxide is absorbed by the vast area of expanse of water in the form of seas but under an optimum condition of temperature. Due to deforestation the situation has become more acute and the solubility in oceans is also decreased by the cause which is the global warming itself. Hence it has become very essential to cut down the emissions into the atmosphere to prevent the alarming rise of global temperatures.

The green house gases can survive in the atmosphere in their molecular state without getting affected by any external agents for a certain period. Here a term known as the atmospheric lifetime is defined which gives an estimation of the time required to restore stability once the natural balance is disturbed by increase in certain atmospheric species. It is given by:

$$T = \frac{m}{Fout + L + D}$$

where m is the mass of the species in kilograms

F_{out} is the natural flow of the species from the atmospheric system in kg/sec

L is the loss of the species due to chemical combination with other elements kg/sec

D is rate of deposition of the species from various sources (in our case CO_2 from thermal power plants) in kg/sec.

This estimation is only a good approximation but cannot be entirely relied upon. Hence, since it is not possible to cut down the power generation to reduce emissions, the alternate way is optimize the generation while keeping the emissions to a minimum level.

3. PROBLEM FORMULATION

The objective of solving economic dispatch problem in an electric power system is to determine the generation levels for all online units which minimize the emission level of the system, while satisfying a set of constraints. This can be formulated as follows:

3.1 Emission Equation

The emission equation of a generating unit is usually described by a quadratic function of power output P_i as follows:

$$E_i(P_i) = d_iP_i^2 + e_iP_i + f_i \text{ kg/hr} \qquad (1)$$

where d_i, e_i, f_i are the emission coefficients of an unit i.

3.2 Power Balance Constraint

The total generation must supply the online demand.

$$\sum(Pi) = Pd$$

where Pd is the load demand.

3.3 Generator Limit Constraints

There will be some upper and lower limits for any generating unit. The power generation of unit n should be in between its minimum and maximum limits only.

$$P_n \min < P_n < P_n \max \qquad (2)$$

where
P_n min is the minimum limit of unit n
P_n max is the maximum limit of unit n.

4. FIREFLY OPTIMIZATION TECHNIQUE

The Fire Fly Optimization Algorithm is based on the bio-chemical and social behaviour of the fireflies. Fireflies produce luminescent flashes as a signal system to communicate with other fireflies, especially to prey attractions. The algorithm has 4 main assumptions. They are:

1. All the fire flies are unisexual, means there are no male and female fire flies as such.
2. Every fire fly communicates with the other flies using the luminous flashes.
3. The attraction is directly proportional to the brightness of the light that the fly emits and which is inversely proportional to the distance between them.
4. No fire fly can attract the brightest fire fly and in fact all the others are attracted to the brightest one.

In this algorithm all the fire flies initially will be at random locations in the search space. Based on the fitness values they produce the light with certain intensity proportional to its fitness. All the fireflies move towards the brighter fire fly and eventually an optimum solution is found in the search space.

The pseudo code for the Fire fly optimization algorithm is as follows:

```
Input :
F(n), n= [n1, n2, n3, ……….]          { objective function }
S= [ $a_k$ , $b_k$ ]for all k=1,2,3,…….,n{ constraints of the problem }
F, G, B, $maxU_i$, $minU_i$          { Algorithm inputs }
```

```
Output:
$X_{i\ min}$        { Resultant global minima point }
Begin;
For i= 1 to F
X(i) => Initialize the positions of the flies
End
Repeat
Begin
i min <= arg $min_i$ $f(x_i)$
Xi min <= arg $min_{xi}$ $f(x_i)$
For i=1 to m do
        For j=1 to m do
                If $f(x_j) < f(x_i)$ then { move firefly i towards }
                $r_j$ <= calculate distance ( $x_i, x_j$ )
                B <= $B_o e^{-Gr}$  { obtain attractiveness }
                $U_i$ <= Generate Random Vector { min $u_i$, max $u_i$ }
                For k=1 to n do
                    X i min,k <= X i min,k + U i min,k
                End
            End
        End
End
U i min <= Generate Random Vector {min $u_i$, max $u_i$ }
For k=1 to n do
    Xi min,k <= Xi min,k + U I min,k
{best firefly should move randomly }
End
Until stop condition true
End
```

5. RESULTS AND EVALUATION

The power system economic dispatch problem based on fire fly optimization technique is tested on standard 3 generator and six generator systems. Multiple generator limits and total emission level of the system is simulated in order to evaluate the correctness and quality of the method.

The emission constants and the generator limits of a 3 generator system are tabulated in TABLE I

TABLE I: EMISSION COEFFICIENTS AND POWER LIMITS OF 3 GENERATOR SYSTEM

Generator	**D_i**	**e_i**	**f_i**	**Pmin**	**Pmax**
Unit 1	0.0126	-1.355	22.983	20	200
Unit 2	0.01375	-1.249	137.370	15	150
Unit 3	0.00765	-0.805	363.704	18	180

The emission constants and the generator limits of a 6 generator system are tabulated in TABLE II.

TABLE II: EMISSION COEFFICIENTS AND POWER LIMITS OF 6 GENERATOR SYSTEM

Generator	D_i	e_i	f_i	Pmin	Pmax
Unit 1	0.0042	0.3300	13.86	10	125
Unit 2	0.0042	0.3300	13.86	10	150
Unit 3	0.0068	-0.5455	40.26	35	225
Unit 4	0.0068	-0.5455	40.26	35	210
Unit 5	0.0046	-0.5112	42.96	130	325
Unit 6	0.0046	-0.5112	42.96	125	315

The simulations are done in MATLAB software. The results obtained for different loads for both 3 generator and 6 generator system are tabulated below.

TABLE III: COMPARISION OD FIRE FLY OPTIMIZATION WITH OTHER TECHNIQUES UNDER VARIOUS LOAD CONDITIONS FOR THREE GENERATOR SYSTEM

Generation MW	Total Emission (Kg/hr)		
	Proposed Method	Particle Swarm Optimization[1]	Conventional Method [1]
200	**446.304**	521.0815	529.26
250	**472.1859**	583.7942	597.499
300	**515.7506**	679.6378	684.826
350	**576.987**	762.1878	791.24
400	**655.9083**	878.5765	916.742

Tables IV and V show the comparison of the performance of the proposed approach with the Particle Swarm Optimization Technique and conventional approach for both three generator and six generator test systems for various values of load demand. The results depicts that the proposed approach shows very good improvement over PSO and conventional approach. Especially the margin that we have gained in large in 3 generator system.

TABLE IV: COMPARISION OD FIRE FLY OPTIMIZATION WITH OTHER TECHNIQUES UNDER VARIOUS LOAD CONDITIONS FOR SIX GENERATOR SYSTEM

Generation MW	Total Emission (Kg/hr)		
	Proposed Method	Particle Swarm Optimization [1]	Conventional Method [1]
500	**252.3889**	251.822	261.634
600	**327.8649**	329.3599	338.992
700	**416.9956**	428.5095	434.38
800	**522.7557**	540.2801	547.796
900	**645.1195**	650.4240	679.24
1000	**784.6992**	793.7640	828.72
1100	**945.5675**	953.3311	996.224

TABLE V: INDIVIDUAL POWERS OF THE THREE GENERATORS FOR VARIOUS DEMANDS

Generation MW	Individual Powers		
	Unit-1	Unit-2	Unit-3
200	67.295	57.812	74.892
250	81.328	70.671	98.004
300	95.359	83.5298	121.115
350	109.39	96.386	144.224
400	123.42	109.244	167.334

TABLE VI: INDIVIDUAL POWERS OF THE SIX GENERATORS FOR VARIOUS DEMANDS

Gen MW	Individual Powers					
	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6
500	35.92	35.92	86.56	85.56	130.0	125.0
600	56.97	56.97	99.56	99.56	143.4	143.4
700	76.73	76.73	111.7	111.7	161.4	161.4
800	96.48	96.48	123.9	123.9	179.5	179.5
900	116.2	116.2	136.1	136.1	197.5	197.5
1000	125.0	138.7	150.0	150.0	218.0	218.0
1100	125.0	150.0	167.9	167.9	244.5	244.5

Figure 1 and Figure 2 show the comparison graphs for emission of carbon dioxide for three generator and six generator test system. The graphs contain the emission (Kg/hr) on the Y axis and Load demand (MW) on the X axis. It is clear from the graphs that the proposed algorithm is better than the conventional approaches.

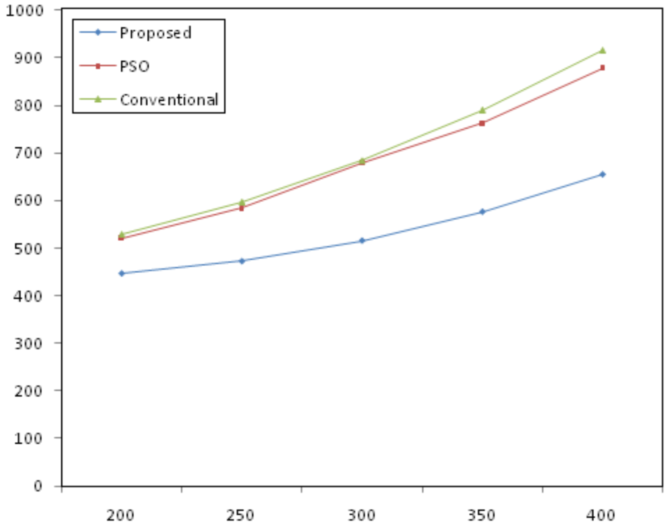

Fig. 1 Comparison of emissions for 3 Gen system

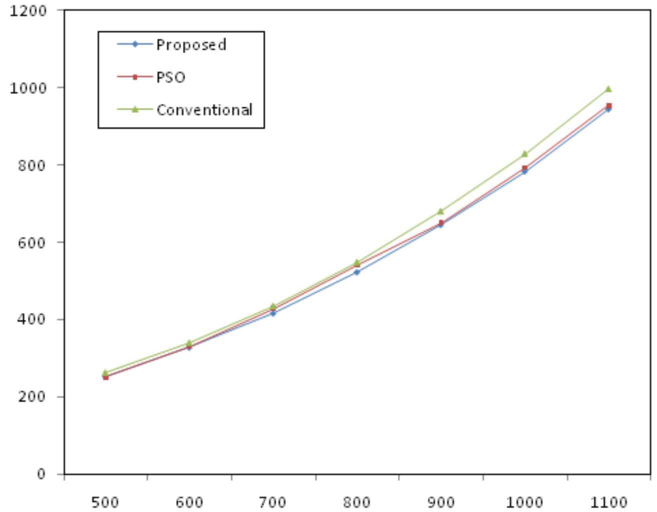

Fig. 2 Comparison of emissions for 6 Gen system

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