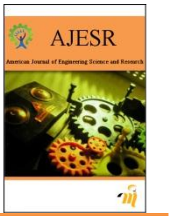
American Journal of Engineering Science and Research

Journal homepage: www.mcmed.us/journal/ajesr



Solution for Combined Economic and Emission Dispatch

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ARTICLE INFO

Received 25/08/2013
Revised 15/09/2013
Accepted 18/10/2013

Key words: Economic Dispatch, Emission Dispatch, Combined Economic and Emission Dispatch (CEED), Security Constrained Combined Economic Emission Dispatch.

ABSTRACT

An efficient and optimum economic operation of electric power generation systems has always occupied an important position in the electric power industry. A power system operation at minimum cost is no longer the only criterion for electrical power dispatch. Combined economic emission dispatch problem is obtained by considering both the economy and emission objectives with required constraints. The purpose of Combined Economic and Emission Dispatch (CEED) is to minimize both the operating fuel cost and emission level simultaneously while satisfying load demand and operational constraints. This paper presents an optimization algorithm, for solving security constrained combined economic emission dispatch problem, through the application of programming method. Many optimization techniques are slow for such complex optimization tasks and are not suitable for on-line use. The proposed method has been tested on IEEE 30-bus test system and found to be suitable for on-line combined economic emission dispatch.

INTRODUCTION

Economic load dispatch is one of the main functions electrical power management system [1]. Electrical power system operation should be characterized by security, reliability and economy. The main objective of economic load dispatch (ELD) is to minimize the fuel cost while satisfying the required equality and inequality constraints.

In recent years the economic dispatch problem has taken a suitable twist as the public has become increasingly concerned with environmental matters. The absolute minimum cost is not any more the only criterion to be met in the electric power generation and dispatching problems. The generation of electricity from the fossil fuel releases several contaminants, such as sulfur oxides (SO2), and oxides of nitrogen (NOX) into the atmosphere. These gaseous pollutants cause harmful effects on human beings as well as on plants and animals.

Nowadays, a large part of energy production is done with thermal sources. Thermal electrical power generating is one of the most important sources of carbon dioxide (CO2), sulfur dioxide (SO2) and nitrogen oxides (NOx) which create atmospheric pollution [2].

Emission control has received increasing attention owing to increased concern over environmental pollution caused by fossil based generating units and the enforcement of environmental regulations in recent years [3]. Numerous studies have emphasized the importance of controlling pollution in electrical power systems [4-14].

Which is the best for optimal solution? Economic load dispatch (ELD), emission dispatch (ED) or combined economic emission dispatch (CEED). To find the correct answer to this question, a good power management strategy is required. Several optimization techniques such as lambda iteration, linear programming (LP), non-linear programming (NLP), quadratic programming (QP) and interior point method (IPM) are employed for solving the security constrained economic dispatch and unit commitment problem [15].

Among these methods, the lambda iteration method has been applied in many software packages due to its ease of implementation and used by power utilities for ELD [16]. Most of the time, alone lambda method does not find optimal solution because of power system

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constraints. Therefore, the lambda method is used in conjunction with other optimization techniques.

The solution of ELD problem using genetic algorithm required large number of iterations/ generations when the power system has large number of units. In order to minimize the number of generations and avoid the loss of useful chromosome for further generation micro genetic algorithm (MGA) was developed [17].

Combined economic and emission dispatch (CEED) has been proposed in the field of power generation dispatch, which simultaneously minimizes both fuel cost and pollutant emissions. When the emission is minimized the fuel cost may be unacceptably high or when the fuel cost is minimized the emission may be high.

In literature as environmental economic dispatch or economic emission dispatch, many algorithms are used to solve CEED problem. Literature [18] proposed a cooling mutation technique in EP algorithm to solve CEED problem for nine units system. Literature [19] validated EP algorithm to solve optimal power flow problem with quadratic and sine component cost functions.

Proposed methods in [20, 21] convert a multi-objective problem into a single objective problem by assigning different weights to each objective. This allows a simpler minimization process but does require the knowledge of the relative importance of each objective and the explicit relationship between the objectives usually does not exist.

In this study two objectives considered are minimizing both fuel cost and environmental impact of emission by using programming based algorithm.

PROBLEM FORMULATION

A. Economic Dispatch

The ELD problem is to find the optimal combination of power generation that minimizes the total fuel cost while satisfying the total demand and power system constraints. The fuel costs for power generation units should be defined. The total fuel cost function of ELD problem is defined as follows:

$$F_T = \sum_{i=1}^{n} f_i(P_i) = \sum_{i=1}^{n} \left(a_i P_i^2 + b_i P_i + c_i \right) \qquad (1)$$

$$F_T = F_1 + F_2 + \ldots + F_K = \sum_{i=1}^{n} F_i \qquad (2)$$

$$P_T = P_1 + P_2 + \ldots + P_K = \sum_{i=1}^{n} P_i \qquad (3)$$

where fi(Pi) is the cost of ith generator in $/h; Pi is the power output of generator i in MW; ai, bi and ci are the cost coefficients of the ith generator.

The total fuel cost function including valve point loading of ELD problem is defined as follows:

$$F_T = \sum_{i=1}^{n} \left(\left(a_i P_i^2 + b_i P_i + c_i \right) + \left| d_i \sin\left(e_i \left(P_{i.\min} - P_i \right) \right) \right| \right) \qquad (4)$$

where FT is the total fuel cost of electrical power generation in $/h; Pi.min is min. power constraint for ith unit in MW; d, e are the fuel cost coefficients of the ith generating unit reflecting the valve-point effect.

B. Emission Dispatch

The solution of ELD problem will give the amount of active power to be generated by different units at a minimum fuel cost for a particular demand. But the amount of emission or is not considered in pure ELD problem. The amount of emission from a fossil-based thermal generator unit depends on the amount of power generated by the unit.

Total emission generated also can be approximated as sum of a quadratic function and an exponential function (5) of the active power output of the generators. The emission dispatch problem can be described as the optimization of total amount of emission release defined by as:

$$E_T = \sum_{i=1}^{n} \left(\left(\alpha_i P_i^2 + \beta_i P_i + \gamma_i \right) + \xi \exp\left(\zeta_i P_i \right) \right) \qquad (5)$$

where ET is total amount of emission (lb/h); αi, βi, γi, ξi and ζi are coefficient of generator emission characteristics.

The total emissions of SO2, CO2 and NOX are represented as follows:

$$E_{SO_2} = \sum_{i=1}^{n} E_{SO_2 i} = \sum_{i=1}^{n} \left(\alpha_{SO_2 i} P_i^2 + \beta_{SO_2 i} P_i + \gamma_{SO_2 i} \right) \qquad (6)$$

$$E_{CO_2} = \sum_{i=1}^{n} E_{CO_2 i} = \sum_{i=1}^{n} \left(\alpha_{CO_2 i} P_i^2 + \beta_{CO_2 i} P_i + \gamma_{CO_2 i} \right) \qquad (7)$$

$$E_{NO_X} = \sum_{i=1}^{n} E_{NO_X i} = \sum_{i=1}^{n} \left(\alpha_{NO_X i} P_i^2 + \beta_{NO_X i} P_i + \gamma_{NO_X i} \right) \qquad (8)$$

C. Combined Economic and Emission Dispatch

The economic dispatch and emission dispatch are two different problems. Emission dispatch can be included in conventional economic load dispatch problems by the addition of emission cost to the normal dispatch cost. In this method different types of emissions are modeled as a cost in addition to the fuel cost. Actually, CEED problem have two objectives. But CEED can be converted into single objective optimization problem by introducing a price penalty factor h ($/lb) as follows:

$$h = \frac{F_T(P_{i.\max}) / P_{i.\max}}{E_T(P_{i.\max}) / P_{i.\max}} \qquad (9)$$

where Pi.max is max. power constraint for ith unit in MW.

$$\text{Minimize } \phi_T = F_T(P) + h.E_T(P) \qquad (10)$$

where φT is the total operational cost of the system subject to the required constraints.

$$\text{Minimize } \phi_T = w_1.F_T(P)+w_2.h.E_T(P) \qquad (11)$$

where w1 and w2 are weight factors. The weight factors w1 and w2 have many implications. For w1 = 1 and w2 = 0 the solution will yield results for pure economic dispatch. For w1 = 0 and w2 = 1 results for pure emission dispatch and for w1 = w2 = 1 results for combined economic emission dispatch can be obtained. The problem can be formulated other form [3, 22] as:

$$\phi_T = w.F_T(P)+(1-w).h.E_T(P) \qquad (12)$$

D. Equality constraint

$$\sum_{i=1}^{n} P_i - P_D - P_L = 0 \qquad (13)$$

where PD is the total power demand and PL is the total transmission loss.

The transmission loss PL can be calculated by using B matrix technique and is defined by as:

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j \qquad (14)$$

where Bij 's are the elements of loss coefficient matrix B.

E. Inequality constraints

The cost is minimized with the following generator capacities and active power balance constraints as;

$$P_{i.\min} \le P_i \le P_{i.\max} \qquad (15)$$

where, Pi.min and Pi.max are the minimum and maximum power generation by ith unit respectively.

$$P_m \le P_{m.\max} \qquad m = 1, \ldots nl \qquad (16)$$

where Pm is magnitude of the line flow in mth line, nl is number of lines.

PROPOSED ALGORITHM FOR COMBINED ECONOMIC AND EMISSION DISPATCH

Mathematical calculations and comparisons to be done very quickly with Delphi, that's why the proposed algorithm in this paper is written in Delphi programming language.

At first power system data and required constraint must be entered into the program. ELD and ED are solved separately. Suitable generating unit's powers are leaved the total demand power after making the ELD and ED. According to the rest of total demand power, ELD and ED are made solution. When the total power demand and required constraints are suitable for all power system, CEED is done. The total fuel cost and emission are calculated with together in CEED step. When the convergence is done the problem will be solved. There is a convergence on the change of circumstances of cost increase or cost decrease. Then, generating unit's powers are saved.

Fig. 1. Flowchart for the proposed CEED method

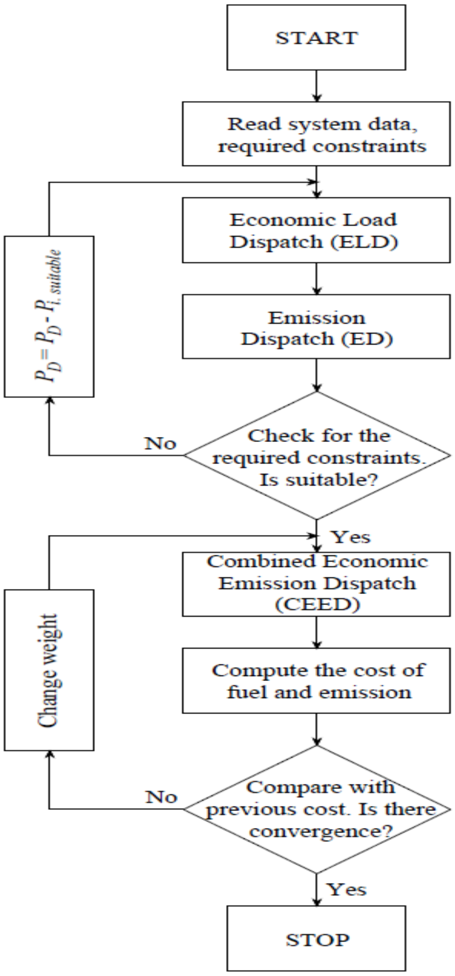
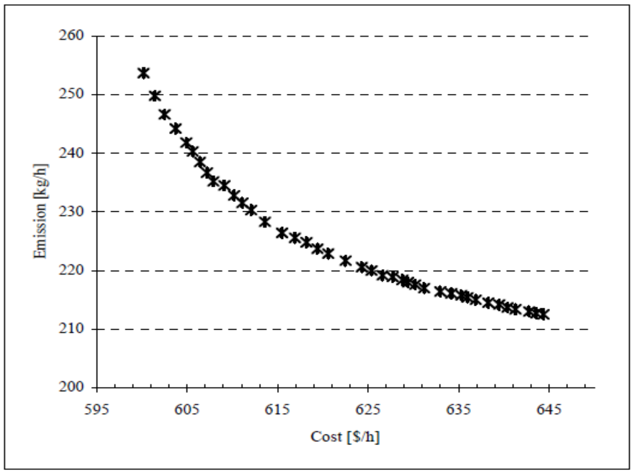


Fig. 2. PCEED solutions for IEEE 30 bus test system



SIMULATION RESULTS AND DISCUSSION

The proposed combined economic and emission dispatch (PCEED) was solved for IEEE 30 bus and 6 generating unit system.

The cost coefficients and power generation limits for the test system are given in Table 1. The NOX emission coefficients are given in Table 2. Test system data are taken from [23].

Table 1. Generator cost coefficients for IEEE 30 bus system

Unit	a	b	c	d	e	Pmin	Pmax
1	100	200	10	15	6283	0.05	0.5
2	120	150	10	10	8976	0.05	0.6
3	40	180	20	10	14784	0.05	1
4	60	100	10	5	20944	0.05	1.2
5	40	180	20	5	25133	0.05	1
6	100	150	10	5	1848	0.05	0.6

Table 2. Generator emission coefficients for IEEE 30 bus system

Unit	α	β	γ	ξ	ζ
1	6,490	-5,554	4,091	2,0e-4	2,857
2	5,638	-6,047	2,543	5,0e-4	3,333
3	4,586	-5,094	4,258	1,0e-6	8,000
4	3,380	-3,550	5,326	2,0e-3	2,000
5	4,586	-5,094	4,258	1,0e-6	8,000
6	5,151	-5,555	6,131	1,0e-5	6,667

Table 3. Results of best fuel cost for the PCEED and 3 approaches

Unit	PCEED	[23]	[29]	[30]
1	0,1098	0,1281	0,1086	0,1168
2	0,2998	0,2702	0,3056	0,3165
3	0,5244	0,5552	0,5818	0,5441
4	10160	10053	0,9846	0,9447
5	0,5240	0,4544	0,5288	0,5498
6	0,3598	0,4453	0,3584	0,3964
Best Cost	600,18	606,66	607807	608245
Emission	0,2537	0,2207	0,22015	0,21664

Table 4. Results of best emission for the PCEED and 3 approaches

Unit	PCEED	[23]	[29]	[30]
1	0,3918	0,3713	0,4043	0,4113
2	0,4603	0,4665	0,4525	0,4591
3	0,5252	0,5642	0,5525	0,5117
4	0,3810	0,3650	0,4079	0,3724
5	0,5467	0,5223	0,5468	0,5810
6	0,5528	0,5783	0,5005	0,5304
Cost	644,40	648,01	642,603	647,251
Best Emission	0,2125	0,1945	0,19422	0,19432

Table 5. CEED solutions

Unit	PCEED	[23]	[29]	[30]
1	0,2245	0,17613	0,2594	0,2699
2	0,3324	0,28188	0,3848	0,3885
3	0,5682	0,54079	0,5645	0,5645
4	0,7066	0,76963	0,7030	0,6570
5	0,5917	0,65019	0,5431	0,5441
6	0,4269	0,44569	0,4091	0,4398
Cost	611,635	612,35	616,069	618,686
Emission	0,22915	0,20742	0,20118	0,19940

SIMULATION RESULTS AND DISCUSSION

The proposed combined economic and emission dispatch (PCEED) was solved for IEEE 30 bus and 6 generating unit system.

The cost coefficients and power generation limits for the test system are given in Table 1. The NOX emission coefficients are given in Table II. Test system data are taken from [23].

The fuel costs of PCEED are found to be better than other methods which are shown in Table 3, 4 and 5. The maximum differences between the PCEED fuel costs with the other method's costs are 8.065, 3.61 and 7.051 respectively. But the emission is not the best. The differences between the best emissions with PCEED are 0.03706, 0.01828 and 0.02975 respectively. PCEED solutions for IEEE 30 bus test system are given in Fig. 2.

The PCEED method is used to simulate the cases on an Intel (R) Core (TM)2 Duo T7300 2GHz laptop computer with 1 GB RAM. Computation time is only about 0.6 s.

CONCLUSION

The proposed multi-objective computer programming based algorithm has been developed to solve CEED problem. The performance of the proposed algorithm is demonstrated for IEEE 30 bus, 6 unit test system. The performance of proposed algorithm is compared with literature [23, 29 and 30]. The results showed that the PCEED method is well suited for obtaining minimum fuel cost.

The differences between the emissions are not very important values. Calculation time of the PCEED algorithm is very less according to genetic algorithm and neural network applications in literature. As a result, PCEED algorithm is acceptable and applicable for CEED problem solution.

ACKNOWLEDGMENT

The authors wish to thank the authorities of PRIST University, Vallam, Thanjavur, Tamil Nadu, India for the facilities provided to prepare this paper.

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