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Combined Economic Dispatch and Emssion Dispatch Using RGA Algorithm

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Abstract: This paper develops efficient and reliable genetic based algorithms to Economic Dispatch, NO_x Emission Dispatch and Combined Economic and Emission Dispatch problems. The thermal power plants pollute air, soil and water. Due to this, the present energy production processes are not ecologically clean. The combination of fossil fuels gives rise to particulate materials and gaseous pollutants apart from discharge of heat to water courses. The three pCrincipal gaseous pollutants, namely carbon-dioxide, oxides of sulfur and nitrogen cause detrimental effects on human beings. This harmful ecological effects caused by the emission of particulate and gaseous pollutants can be reduced by adequate distribution of load between the plants of a power system. For successful operation of the system subject to ecological and environmental constraints, algorithms have been proposed for minimum cost, minimum NO_x emission and combined economic and emission dispatches. These are based upon quadratic type objective function and the solution gives the optimal dispatch directly. In the present work, a price penalty factor is introduced which blends the emission cost with normal fuel cost. This avoids the use of two classes of dispatching and the need to switch over between them. The SGA and conventional methods are applied for the successful operation of the power system subject to economic and emission dispatch. The Refined Genetic Algorithm (RGA) method is tested for a six-unit thermal power system and the results are compared with the solutions obtained from classical simple non-iterative technique and Simple Genetic Algorithm (SGA) method. The software packages for the various algorithms are developed in C-language.

Key words: Component · Formatting · Style · Styling

INTRODUCTION

The Resource scheduling problem is divided into two stages, the commitment stage and the constrained economic dispatch stages. The OPF constraints that are relevant to the active power such as transmission capacity constraints, different types of emission requirements (i.e. SO2 and NOx), emission caps for certain areas of the system and the total system emission as well as fuel. To obtain fast and efficient solutions, the constrained economic dispatch problem is decomposed into sub problems, each corresponding to constrained economic dispatch of committed units at a given period.

Economic power dispatch is a common problem pertaining to the allocation of the amount of power to be generated by different plants in the system on an optimum economy basis. The existing energy production processes are not ecologically clean. For instance thermal power plants pollute air, soil and water. The combustion of fossil fuels gives rise to particulate materials and gaseous pollutants apart from discharge of heat to water courses.

The optimization technique used in this paper work for economic and emission dispatch models is done based on the solution of the familiar coordination equations. This technique is a direct one [1-7] which circumvent the iterative approach. For successful operation of the system subject to economical and environmental constraints, algorithms have been proposed for minimum cost, minimum NOx emission and minimum combined dispatches [8].

In the section I the new conventional algorithm is applied to minimum cost, minimum emission and combined minimum cost and minimum emission. So, the combined economic and emission dispatch gives a closer reduced cost compared to separate minimum cost and minimum emission dispatches. In the section II of the paper, refined

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genetic algorithm is implemented to solve the above mentioned three dispatch models and the results are compared with the solutions obtained from the conventional method and simple genetic algorithm [9, 10].

Formulation of Dispatching Strategies

Problem Formulation: This section develops the formulation of objective function and constraints for economic dispatch, minimum NOX emission dispatch and combined economic and emission dispatch methods [11].

Economic Dispatch: The fuel cost of a thermal plant can be regarded as an essential criterion for economic feasibility. The fuel cost curve is assumed to be approximated by a quadratic function of generator active power output as

$$F_i = a_i P^2 i + b_i P_i + C_i, Rs/h \qquad \text{[Eq.1]}$$

The economic dispatch problem is defined as to minimize

$$F_i = \sum_{i=1}^{N} (a_i P^2 i + b_i P_i + c_i), Rs/h. \qquad \text{[Eq.2]}$$

$$i = 1,2,3.........n$$

where F_t is the total fuel cost in the system (Rs/h), P_t the power output of i[th] generating unit (MW), a_i, b_i, c_i the fuel cost coefficients of i[th] unit and N is the number of thermal units. This is subject to

- The operating constraints, that is, plant capacity constraints

$$P_{iMin} <= P_i <= P_{iMax} \qquad \text{[Eq.3]}$$

$$i = 1,2,3.........n$$

where $P_{i\min}$ is the minimum power output of i[th] unit (MW) and $P_{i\max}$ the maximum power output of i[th] unit (MW); and

- The system demand constraint

$$\sum_{i=1}^{N} P_i = P_D + P_L \qquad \text{[Eq.4]}$$

where P_D is the total system power demand (MW) and P_L the total transmission losses (MW) calculated by average loss formula coefficients.

Minimum NO_X Emission Dispatch: The economic dispatch is well recognized and will minimize total fuel cost while meeting total load plus transmission losses and generator limit constraints. Emission constraints may be violated. Minimum emission strategy can be implemented by direct substitution of an incremental emission curve for an incremental cost curve in a conventional economic dispatch algorithm.

The amount of NOx is given [1-3] as a function of generator output, that is, the sum of quadratic and exponential functions. This complex function is successfully approximated into a simple quadratic function of the form

$$E_i = (d_i P_i^2 + e_i P_i + f_i), Rs/h \qquad \text{[Eq..5]}$$

where N is the number of thermal units and E_i the NO_X emission of i[th] unit (Kg/h).

The minimum NOx emission dispatch problem is defined as to minimize

$$E_i = \sum_{i=1}^{n} (d_i P_i^2 + e_i P_i + f_i), Kg/h \qquad \text{[Eq.6]}$$

where E_i is the total NO_x emission (Kg/h), P_i the power output of the i[th] generator (MW); d_i, e_i, f_i the NO_x emission coefficients of ith unit and N the number of thermal units. This is subject to the generating unit constraint Eq.3 & load constraint Eq..4.

The minimum NO_X emissions are possible by proper generator scheduling which may cause a further fuel expense and the increase in operating cost [12, 13].

Combined Economic & Emission Dispatch: In minimizing total emission, local constraints may become intolerable, necessitating a shift away from minimum total emission to meet local constraints. So the problem of choosing the least cost generating schedule with environmental objectives still remains and so a combined economic and environmentally satisfied dispatch method is rather sensible than separate minimum emission as well as cost dispatches [14, 15].

The NOx emissions of the thermal units are given by

$$E_i = d_i P_i^2 + e_i P_i + f_i, Kg/h \qquad \text{[Eq.7]}$$

The emissions are converted into monetary units by inventing a price. That is, the emission costs are blended with the normal fuel costs with the use of the price factor defined as the price penalty factor g.This avoids the problem of dispatching and After the introduction of the price penalty factor, the total operating cost of the system is the cost of fuel plus the implied cost of NOx emission. So, the combined economic emission dispatch problem is defined as to minimize

$$\min imize\phi_t = \sum_{i=1}^{N} F_i + g\sum_{i=1}^{N} E_i \quad \text{[Eq.8]}$$

where g = price penalty factor (Rs/Kg), which is the cost incurred to reduce 1 kg of NO_x emission output. This is subject to the generating unit constraint

Price Penalty Factor: A *price penalty factor* (g) is a price factor which blends the emission costs with the normal fuel costs. This avoids the use of two classes of dispatching and need to switch over between them. After the introduction of the price penalty factor, the total operating cost of the system is the cost of fuel plus the implied cost of NO_x emission.

This value is calculated as follow for a system operating with a load of PD MW

- The average cost of each generator is evaluated at its maximum output, that is,

$$\frac{F_i(P_{i\max})}{P_{i\max}} = \frac{a_iP_{i\max}2 + b_iP_{i\max} + c_i}{P_{i\max}}, Rs/Mwh \quad \text{[Eq.9]}$$

- The average NOx emission of each generator is evaluated at its maximum output, that is,

$$\frac{E_i(P_{i\max})}{P_{i\max}} = \frac{d_iP_{i\max}2 + e_iP_{i\max} + f_i}{P_{i\max}}, Kg/Mwh \quad \text{[Eq..10]}$$

- By dividing the average cost of each generator by its average NOx emission, the price penalty factor is,

$$\frac{F_i(P_{i\max})/P_{i\max}}{E_i(P_{i\max})/P_{i\max}} = \frac{\mathrm{aiPimax}^2 + \mathrm{biPimax} + \mathrm{ci})}{d_iP_{i\max}{}^2 + e_iP_{i\max} + f_i)} = g_i,(Rs/Kg) \quad \text{[Eq.11]}$$

- Obtained gi is arranged in ascending order,
- The maximum capacity of each unit (P_{imax}) is added one at a time, starting from the smallest g_i unit, until $\sum P_{i\max} \geq PD$.
- At this stage, g_i associated with the last unit in the process is the price penalty factor g (Rs/Kg) for the given load.

Economic dispatch Algorithm: For minimum economic dispatch, the fuel cost is expressed as a quadratic equation of the form

$$F_i = a_iP^2{}_i + b_iP_i + C_i, Rs/h \quad \text{[Eq.12]}$$

where F_i is the fuel cost of i^{th} generating unit. a_i, b_i, c_i are the fuel cost coefficients.

The solution of the below quadratic equation gives the value of λ directly.

$$\sigma_1\lambda^2 + \sigma_2\lambda + \sigma_3 - P_D = 0 \quad \text{[Eq.13]}$$

Where σ_1, σ_2, σ_3 are the functions of fuel cost and transmission loss coefficients and λ the incremental cost of received power (Rs/MWh).

Substitution of the value of λ in equation Eq.13 gives the individual plant generations for the given power demand P_i

$$P_i = (\alpha_i\lambda^2 + \beta_i\lambda + \gamma_i), MW \quad \text{[Eq.14]}$$

I=1, 2, 3 …n

where α_i, β_i, γ_i are the functions of fuel cost coefficients of i^{th} plant and transmission loss coefficients.

Substituting the plant generations in their fuel cost equations and summing up gives the fuel cost. At optimum dispatch if the capacity constraint of any unit is violated, generation re-dispatch is done as below.

Minimum NOx Emission Dispatch Algorithm: For minimum NO_X emission dispatch, the amount of nitrogen oxides emission is expressed as a quadratic function of the form

$$E_i = d_iP_i^2 + e_iP_i + f_i, Kg/h \quad \text{[Eq.15]}$$

where E_i is the NOx emission of plant i, di, ei, fi the NOx emission coefficients and n, the number of thermal plants. The same equation (15) can be directly applied for minimum emission dispatch. While computing the coefficients, the fuel cost coefficients are replaced by the NOx emission coefficients.

The minimum NO_x emission dispatch algorithm is similar to the minimum cost algorithm except, the computation of coefficients σ_1, σ_2, σ_3 α_i, β_i and γ_i; these are calculated with the NO_x emission coefficients. The minimum NO_x emissions are possible by proper generator scheduling which may cause a further fuel expense and the increase in operating cost.

Combined Dispatch Algorithm: Once the value of the price penalty factor is known, Eq.8 can be rewritten in terms of known coefficients and the unknown outputs of the generator

$$\phi t = \sum_{i=1}^{N}[(ai + gdi)Pi^2 + (bi + gei)Pi + (Ci + gfi)]Rs / h. \qquad \text{[Eq.16]}$$

This has the resemblance of the fuel cost equation Eq.3.2 and the coefficients σ_1, σ_2, σ_3 α_i, β_i and γ_i are calculated with the value of (a_i+gd_i),(b_i+ge_i) and (c_i+gf_i). The solution of the quadratic equation gives the value of λ and hence the individual plant generation is obtained by equation Eq.3.15. Both the fuel cost and the NO_x emission output can be had with this scheduling. The results reveal that for a system demand P_D, there is a reduction in fuel cost compared to economic dispatch.

The problem reduces to a simple economic dispatch problem once the price penalty factor is determined. By proper scheduling of generating units, comparative reduction is achieved in both total fuel cost and NO_X emission.

Genetic Algorithms: Genetic Algorithm (GA), first introduced by John Holland in early seventies, is becoming a flagship among various techniques of machine learning and function optimization. Algorithm is a set of sequential steps needs to be executed in order to achieve a task. A GA is an algorithm with some of the principles of genetics included in it. The genetic principles "Natural Selection" and "Evolution Theory" are main guiding principles in the implementation of GA. The GA combines the adaptive nature of the natural genetics and search is carried out through randomized information exchange [16].

There is multitude of search techniques. Among them Calculus-based, Enumerative and Random search technique are mostly used. The first two techniques i.e. Calculus- based and Enumerative are capable of arriving at reasonable good solutions for search spaces of smaller sizes. But once they are confronted with search spaces of enormous size and wide variation from point to point in their precinct, like all practical systems, their efficiency in delivering solutions is drastically low. These are insufficiently robust to be used as solution techniques for complex problems involving huge search space due to their lack of ability to overcome the local optimum points and reach the global optimum point. It is important to note that this randomized search is not a directionless search. The search is carried out randomly and information gained from a search is utilized in guiding the next search. Genetic Algorithms is an example of such search techniques [17, 18].

Genetic Algorithms surpass all the above limitations of conventional algorithms by using the basic building blocks that are different from those of conventional algorithms. It is different from them in the following aspects.

- GA works with a coding of the parameter set and not the parameters themselves.
- GA searches from a population of point and not from a single point like conventional algorithms.
- GA uses objective function information, not derivative or other auxiliary data.

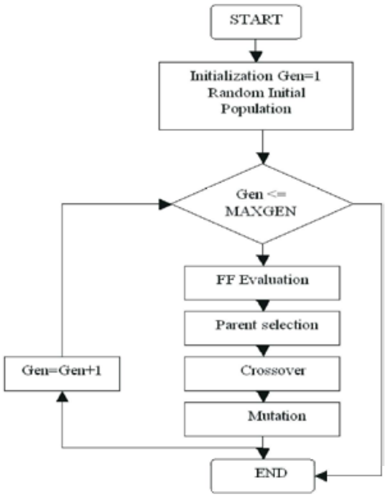
TYPES OF Genetic Algorithms: Based on different combinations of operators and strategies, GA's are classified into three types.

Simple Genetic Algorithm: In this multipoint crossover and mutation are the operators used and Roulette Wheel Selection is the selection technique.

Refined Genetic Algorithm: In this uniform crossover and mutation are the operators and Roulette Wheel election is the selection technique. Strategies like Elitism, changing P_C and P_m are also implemented.

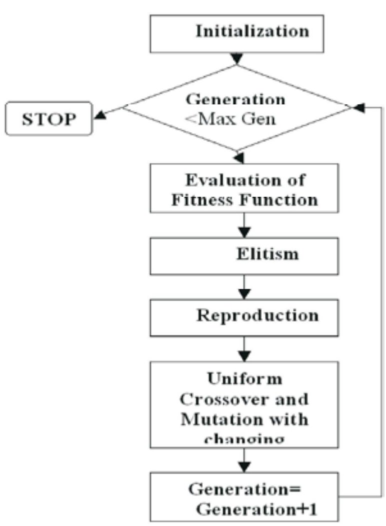
Crowding Genetic Algorithm: This consists of uniform crossover and mutation, random selection technique and strategies like parent replacement, changing P_c and P_m are also implemented.

Flow Chart for Genetic Algorithm



Refined Genetic Algorithm: David Goldberg's Simple Genetic Algorithm (SGA) is a suitable method for solving most optimization problems. The results produced are acceptable, yet still imperfect. Since loss of accuracy increase cost, especially with respect to the ED problem, it is beneficial to find new techniques which will boost the performance capability of SGA. Elitism was added to the SGA leads to Refined Genetic Algorithm (RGA) [14] and observed an improvement in the results of Simplified Genetic Algorithm (SGA).After determining that the chance of aforementioned GA program's converging on the optimal solution was problematic, several modification techniques were applied to both the RGA and the Simplified Genetic Algorithm with elitism (SGAE) to try their efficiency and accuracy.

Flow chart for Refined Genetic Algorithm



Objective and Fitness Function Formulation: In the Combined Economic Emission Dispatch problem, the goal is to minimize the *objective function*

$$F_{obj} = \sum_{i=1}^{N} Fi(Pi) + g\sum_{i=1}^{N} Ei(Pi) \quad \text{[Eq.17]}$$

with the constraint of equality

$$\sum_{i=1}^{N} P_i - P_{loss} - P_{loads} = 0 \quad \text{[Eq.18]}$$

is changed to unconstrained optimization problem and thus forming the *fitness function*

$$F_{cr} = \sum_{i=1}^{N} Fi(P_i) + g\sum_{i=1}^{N} E_{ij}(P_i) + PF(\sum_{i=1}^{N} P_i - P_{loss} - P_{load}) \quad \text{[Eq.19]}$$

Evaluation of Fitness Function: The evaluation is a procedure to determine the fitness of each string in the population and is very much application oriented. Since the GA proceeds in the direction of evolving better fit strings and the fitness value is the only information available to the GA, the performance of the algorithm is highly sensitive to the fitness values. In case of optimization problems the fitness is the value of the objective function to be optimized. GA's are basically unconstrained search procedures in the given problem domain. Any constraints associated with the problem could be incorporated into the objective function as a penalty functions. The objective function is to minimize fuel cost and NO_X emission. So the Fitness function is taken as

$$\text{Fit[i]} = 1.0 / (\sum_{i=1}^{N} F_i\ (P_i) + g\sum_{i=1}^{N} E_{ij}\ (P_i) + PF \quad \text{[Eq.20]}$$

where
N = Number of generating units
PF = Power balance penalty factor
g = Price penalty factor (Rs/Kg)

The price penalty factor is introduced to merge the emission cost in the fitness function.

D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}

Comparision of Results: The present work developed new conventional algorithms for minimum cost, minimum emission and combined dispatches. They are based upon a quadratic function and the solution gives the optimal dispatch directly. These results are compared with the results of reliable and efficient genetic algorithms and tested for the following standard genetic parameters and the results are noted for different demands.

COMPARISION OF RESULTS OBTAINED BY ALGORITHMS

Total System Load=500MW

Method	Dispatch Algorithm	Fuel Cost (Rs/h)	NO_x Emission (Kg/h)	Power Loss (MW)
Conventional Method	Min. Cost	27533.7	278.3	278.3
SGA		27450.1	272.5	272.5
RGA		27366.6	270.5	270.5
Conventional Method	Min. Emission	27853.3	262.3	10.71
SGA		27734.8	262.3	10.35
RGA		27676.13	262.1	10.05
Conventional Method	CEED Cost	27710.00	263.6	10.97
SGA		27632.3	263.1	10.77
RGA		27592.0	262.8	10.52

Comparison of Percentage Cost and NO_X Output:

Minimum Cost Dispatch as Reference

Minimum emission dispatch	1.14% more
Combined dispatch	0.51% more

Minimum Emission Dispatch as Reference

Minimum cost dispatch	6.09% more
Combined dispatch	0.49% more

From the results of minimum cost and minimum emission dispatches, it is found that there is an increase in fuel cost of Rs 319.5/h and a reduction in NO_X emission rate of 16.0 (Kg/h). That is a switch over from economic load dispatch to emission dispatch leads to a 6.09% reduction in NOx emission from power station at an increase of 1.14% in total fuel cost.. When the transmission losses are compared, minimum emission dispatch offers reduced transmission losses which are an advantageous aspect in the transmission line reliability point of view.

Total System Load=1100MW

Method	Dispatch Algorithm	Fuel Cost (Rs/h)	NO_x Emission (Kg/h)	Power Loss (MW)
Conventional Method	Min. Cost	58561.7	1226.8	57.09
SGA		58174.4	1187.5	49.48
RGA		57955.6	1166.2	45.55
Conventional Method	Min. Emission	60946.4	1032.2	51.17
SGA	59762.5	991.5	22.45	
RGA	59668.7	989.5	21.77	
Conventional Method	CEED Cost	61168.9	1043.4	43.87
SGA		61119.3	1042.7	51.86
RGA		60972.4	1039.4	51.10

Comparison of Percentage Cost and NO_X Output

Minimum Cost Dispatch as Reference

Minimum emission dispatch	3.91% more
Combined dispatch	0.36% more

Minimum Emission Dispatch as Reference

Minimum cost dispatch	18.85% more
Combined dispatch	1.73% more

From the results of minimum cost and minimum emission dispatches, it is found that there is an increase in fuel cost of Rs 2384.7/h and a reduction in NO_X emission rate of 194.6 (Kg/h). That is a switch over from economic load dispatch to emission dispatch leads to an 18.85% reduction in NOx emission from power station at an increase of 3.91% in total fuel cost. When the transmission losses are compared, minimum emission dispatch offers reduced transmission losses which are an advantageous aspect in the transmission line reliability point of view.

So, the combined economic and emission dispatch gives a closer reduced cost dispatch with environmentally satisfied NO_X output, compared to separate minimum cost and minimum emission dispatches.

CONCLUSIONS

This paper developed a new computational algorithms for minimum cost, minimum emission and combined minimum cost and minimum emission. Their applicability has been tested with the help of a sample system and the results are compared. Operating constraints, system demand constraints are incorporated in the optimization methodology. Minimum cost dispatch gives a saving in fuel cost with a higher NOX emission output. Minimum emission dispatch algorithm gives a reduction in NOX emission by proper generator scheduling. For combined economic and emission dispatch, the introduction of price penalty factor(g) avoids the use of two classes of dispatching and need for switch over between them. The results generate a reduced NOX emission output with a marginal increase in cost in combined dispatch methodology.

The SGA and RGA algorithms are implemented for the determination of the global or near global optimal solution. The results of these genetic based algorithms are compared with the conventional method. Since, the conventional method depends on the exact adjustment of lamda value, it can not give accurate solutions. The genetic algorithms offer less cost compared with the conventional method. Thus it develops a simple tool for the power industry to aid in curbing air pollution and hostile environment which are harmful to the welfare of society.

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