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Application of Genetic Algorithm to Solve Emission Constrained Economic Dispatch Problems

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Abstract: This paper proposes a Genetic Algorithm (GA) method to solve Emission constrained Economic dispatch problems. The proposed method is applied to solve the Economic Load Dispatch (ELD), Emission Dispatch (ED), Combined Economic and Emission Dispatch (CEED), Economic Constrained Emission Dispatch (ECED) problems. For validating the proposed method it has been tested on IEEE 30 bus system with 6 generators. The results obtained with the proposed method are compared with the conventional method.
Keywords: Genetic algorithm , Economic Load Dispatch Emission Dispatch ,Combined Economic and Emission Dispatch , Economic Constrained Emission Dispatch , Conventional method

I. INTRODUCTION

Electrical power is an essential requirement for all facets of our life and has been recognized as a basic human need. It is the critical infrastructure on which the socio-economic development of the country depends. The growth of the economy and its global competitiveness hinges on the availability of reliable and quality power at competitive rates. The demand of power in India is enormous and is growing steadily. The vast Indian power market, today offers one of the highest growth opportunities for private developers.

Our Country is endowed with a wealth of rich natural resources and sources of energy. Resources for power generation are unevenly dispersed across the country. This can be appropriately and optimally utilized to make available reliable supply of electricity to each and every household. Electricity is considered key driver for targeted 8 to 10 % economic growth of India [13]. Electricity supply at globally competitive rates would also make economic activity in the country competitive in the globalized environment.

India is both a major energy producer and consumer. India currently ranks as the world's eleventh greatest energy producer & world's fifth greatest energy consumer [12]. The country, though rich in coal and abundantly endowed with renewable energy in the form of solar, wind, hydro and bio-energy has very small hydrocarbon reserves (0.4% of the world's reserve). India, like many other developing countries, is a net importer of energy, more than 25 percent of primary energy needs being met through imports mainly in the form of crude oil and natural gas.

The distribution of primary commercial energy resources in India is quite skewed. 70 percent of the total hydro potential is located in the Northern and Northeastern regions, whereas the Eastern region accounts for nearly 70 percent of the total coal reserves in the country. The Southern region, which has only 6 percent of the total coal reserves and 10 percent of the total hydro potential, has most of the lignite deposits occurring in the country. For India, coal is the dominant fuel, accounting for 51.4% of 2007 primary energy demand (PED), followed by oil at 31.8%, gas at 8.9% and hydro-power with a 6.8% share of PED [14].

II. GROWTH OF POWER SECTOR

Growth of Power Sector infrastructure in India since its Independence has been noteworthy making India the third largest producer of electricity in Asia. Generating capacity has grown manifold from 1,362 MW in 1947 to 1, 47,402.81 MW (as on December 2008).

In its quest for increasing availability of electricity, India has adopted a blend of thermal, hydel and nuclear sources. Out of these, coal based thermal power plants and in some regions, hydro power plants have been the mainstay of electricity generation. Oil, natural gas and nuclear power accounts for a smaller proportion. Of late, emphasis is also being laid on non-conventional energy sources i.e. solar, wind and tidal.

The level of development in a society is strongly dependent on the level of energy availability and growth rate in energy use in any country depends on its current level of development. The energy use in developed countries is projected to grow slowly, while it is growing very fast in the developing countries. The growth rates of the primary energy and electrical energy have been estimated as follows [15].

Energy is a vital input for the social and economic development of any country. India has been witnessing an exponential growth over the years. Large scale consumption of the non renewable commercial energy sources has resulted in environmental degradation. Hence the situation calls for proper energy planning so as to effectively leverage on the available commercial energy sources in an environment friendly manner [16]. The problems, which are related to the above said issues, are identified and they are unit commitment, economic load dispatch, emission constrained economic dispatch, combined heat and power economic dispatch and maintenance scheduling. The optimization of the above said problems determines the efficiency, economy, stability and reliability of the power system.

III. OBJECTIVE

The main objective of this work is to apply Genetic algorithm to solve the Economic Load Dispatch (ELD), Emission Dispatch (ED), Combined Economic and Emission Dispatch (CEED), Economic Constrained Emission Dispatch (ECED) problems to get an optimal solution.

IV. ECONOMIC LOAD DISPATCH PROBLEMS

Economic Load Dispatch problem is one of the power system optimization problems, having non linear characteristics with heavy equality and inequality constraints that make the problem of finding the global optimum difficult using any mathematical programming and optimization techniques. The ELD problem is a sub problem of unit commitment and a constrained optimization one. The fundamental requirement of ELD is to determine the optimal output of generating units so as to meet the load demand at the minimum operating cost under various systems and operating conditions.

The ELD problem is about minimizing the fuel cost of generating units for a specified period of operations so as to accomplish optimal dispatch among the committed units and in return satisfying the system constraints. The constrained ELD problem is subjected to a variety of constraints depending upon assumptions and practical implications like power balance constraints, generator output constraints, ramp rate limits and prohibited operating zones.

V. EMISSION DISPATCH PROBLEMS

Traditionally electric power plants are operated on basis of least fuel cost strategies and only little attention is paid on the pollution produced by the plants. The generation of electricity from fossil fuel releases several contaminants, such as, Sulphur Oxides (SO_2), Nitrogen Oxides (NOx) and Carbon Dioxide (CO_2). Emission dispatch refers to minimization of emission produced by generating units. Reduction of pollution levels by changing the generation allocation however increases the fuel cost.

VI. COMBINED EMISSION AND ECONOMIC DISPATCH PROBLEMS

With the passage of ‘Clean Air Act Amendments of 1990’, environmental constraints have topped the list of utility management concerns**.** In the recent years, environmental constraints started to be considered as part of electric system planning. That is, minimization of pollution emission (SOx, NOx, CO_2, etc) in case of thermal power plants. The modern operational strategies of the generating plants now include reduction of pollution level up to safe limit, in addition to minimum fuels cost strategy. This is known as Combined Emission and Economic dispatch.

VII. EMISSION CONSTRAINED ECONOMIC DISPATCH PROBLEMS

In this type of problems the emission level is restricted to certain limits. These constraint limits are to be considered in such problems. Due to the environmental concerns that arise from the emissions produced by fossil fuelled power plants, the classical economic dispatch, which operates power systems so as to minimize only the total fuel cost, can no longer be considered alone. Thus, by environmental dispatch, emissions can be reduced by dispatch of power generation to minimize emissions. The economic dispatch problem has been most commonly solved by a deterministic approach.

VIII. REVIEW OF EVOLUTIONARY COMPUTING TECHNIQUES

A. Genetic Algorithm

Genetic algorithms are adaptive heuristic search algorithms premised on the evolutionary ideas of natural selection and genetics. The basic concepts of GAs are designed to simulate processes in natural system necessary for evolution, specifically those that follow the principles first laid down by Charles Darwin of survival of the fittest. As such they represent an intelligent exploitation of a random search within a defined search space to solve a problem.

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First pioneered by John Holland in 1960, Genetic algorithms have been widely studied, experimented and applied in many fields in engineering world. Not only does GAs provide alternate methods for solving problems, it consistently outperforms other traditional methods. Many of the real world problems involved finding optimal parameters, which might prove difficult for traditional methods but ideal for GAs. They can solve problems that do not have a precisely defined solving methods, or if they do, when following the exact solving method would take far too much time.

Three basic operators comprise a GA. They are reproduction, crossover and mutation. Reproduction is the mechanism by which the most highly fit members in a population are selected to pass on information to the next population of members. It effectively selects the fittest of the strings in the current population to be used in generating the next population. In this way, relevant information concerning the fitness of a string is passed along to successive generations. It can be shown that GAs actually allocate exponentially increasing trials to the most fit of these strings. Crossover serves as a mechanism by which strings can exchange information, possibly creating more highly fit strings in the process and allowing the exploration of new regions of the search space. There are many types of crossovers are available like single point crossover, multipoint crossover, uniform crossover and window crossover.

Comparison of GA with Conventional methods:

The GAs can be distinguished from other optimization methods in the four different ways as follows:

1) GAs use objective function information to guide the search, not derivatives or other auxiliary information.
2) GAs uses a coding of the parameters used to calculate the objective function in guiding the search, not the parameter themselves.
3) GAs search through many points in the solution space at one time, not a single point.
4) GAs use probabilistic rules, not deterministic rules, in moving from one set of solutions (a population) to the next.

B. Evolutionary Programming (Ep)

Evolutionary programming, originally conceived by Lawrence J. Fogel in 1960, is a stochastic optimization strategy similar to Genetic algorithms, but instead places emphasize on the behavioral linkage between parents and their offspring, rather than seeking to emulate specific genetic operators as observed in nature. Evolutionary programming is similar to Evolution strategies, although the two approaches developed independently. Like both ES and GAs, EP is a useful method of optimization when other techniques such as gradient descent or direct, analytical discovery are not possible. Combinatorial and real-valued function optimization in which the optimization surface or fitness landscape is “rugged”, processing many locally optimal solution, are well suited for evolutionary programming. D.B. Fogel has given a detailed explanation about the Evolutionary programming and demonstrated it with suitable illustrations. H.T Yang et al have used the EP method for solving economic load dispatch with non-smooth fuel cost functions. L.L. Lai et al have demonstrated the effectiveness of EP by applying it for the reactive power planning with network contingencies. K.A. Juste et al have solved the unit commitment problem by the EP method.

There are two important ways in which EP differs from GAs.

1) There is no constraint on the representation in EP. The typical GA approach involves encoding the problem solutions as string of representative tokens, the genome. In EP, the representation follows from the problem. A neural network can be represented in the same manner as it is implemented because the mutation operation does not demand a linear encoding.
2) The mutation operation simply changes the aspects of solution according to a statistical distribution which weights minor variations in the behavior of the offspring as highly probable and substantial. Further, the severity of mutations is often reduced as the global optimum is approached. There is a certain tautology here: if the global optimum is not already known, how can the spread of the mutation operation be damped as the solutions approach it? Several techniques have been proposed and implemented which address this difficulty, the most widely studied being the “Meta-evolutionary” technique in which the variance of the mutation distribution is subject to mutation by a fixed variance mutation operator and evolves along with the solution.

C. Economic Load Dispatch Problem

1) Introduction

Economic Load Dispatch problem is one of the power system optimization problems, having non linear characteristics with heavy equality and inequality constraints that make the problem of finding the global optimum difficult using any mathematical programming and optimization techniques. Usually, the ELD problem is a sub problem of unit commitment and a constrained optimization one. The fundamental requirement of ELD is to determine the optimal output of online generating units so as to meet the load demand at the minimum operating cost under various systems and operating conditions.

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The ELD problem is about minimizing the fuel cost of generating units for a specified period of operations so as to accomplish optimal dispatch among the committed units and in return satisfying the system constraints. The constrained ELD problem is subjected to a variety of constraints depending upon assumptions and practical implications like power balance constraints, generator output constraints, ramp rate limits and prohibited operating zones.

2) *Objective function:* The objective function of ELD reflects the costs associated with generating power in the system. The quadratic cost model is used. The objective function for the entire power system can then be written as the sum of the quadratic cost model for each generator

$$F = \sum_{i=1}^{n_g} a_i + b_i P_i + c_i P_i^2 \left[Rs/h \right]$$

Where,

n_g - number of thermal units

P_i - active power generation at unit *i*

a_i , b_i , c_i - cost coefficients of the i^{th} generator

In case of a combined cycle cogeneration plant, two types of fuel cost functions are considered.

$$F_i(P_i)_{quadratic} = a_i P_i^2 + b_i P_i + c_i [Rs/h]$$

$$F_i(P_i)_{CCCP} = b_k P_i + c_k [Rs/h] \quad \text{Linear Region}$$

$$= K [Rs/h] \quad \text{Constant Region}$$

3) *Constraints***:** Thermal units require crew to operate them, especially when turned on and off. A thermal unit undergoes gradual temperature changes, and this translates into a time period of few hours required to bring the unit on line. As a result most of the constraints that arise in ELD problem are based on these restrictions on thermal unit

4) *Power balance constraint*

This is based upon the principle that the total generation $\sum_{i=1}^{n_g} (P_i)$ should be equal to the total system demand P_D plus the transmission network loss P_{loss}. This is represented by

$$\sum_{i=1}^{n_g} (P_i) = P_D + P_{loss}$$

The transmission losses must be taken into account in order to achieve true economic dispatch. To calculate the transmission losses, B coefficients method is used in general. This is given by

$$P_{loss} = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_i B_{ij} P_j + \sum_{i=1}^{n_g} B_{0i} P_i + B_{00}$$

Where,

P_D - Load demand (MW)

P_i - Real power produced by the unit 'i' (MW)

5) *The generator constraint*

The generation output of each unit should be between its minimum and maximum limits. That is, the following inequality constraint for each generator should be satisfied

$$P_{i_{\min}} \le P_i \le P_{i_{\max}}, i = 1 \ldots, n_g$$

Where
P_i is the power output of the i[th] generator
$P_{i\,min}$, $P_{i\,max}$ is the minimum and maximum real power output of i[th] generator
The maximum active power generation of a source is limited by thermal consideration and also minimum power generation is limited by the flame instability of a boiler. If the power output of a generator for optimum scheduling of the system is less than a pre-specified value P_{min}, the unit is not put on the bus bar because it is not possible to generate that low value of power from that unit.

IX. EMISSION DISPATCH PROBLEM

A. Introduction

Traditionally electric power plants are operated on basis of least fuel cost strategies and only little attention is paid on the pollution produced by the plants. The generation of electricity from fossil fuel releases several contaminants, such as, Sulphur Oxides (SO_2), Nitrogen Oxides (NOx) and Carbon Dioxide (CO_2). Emission dispatch refers to minimization of emission produced by generating units. Reduction of pollution levels by changing the generation allocation however increases the fuel cost.

B. Objective Function

The objective function of Emission dispatch reflects the emission release associated with generating units in the system. The objective function for the entire power system can then be written as the sum of emission release from each generator:

$$E = \sum_{i=1}^{n_g} d_i + e_i P_i + f_i P_i^2 \left[kg/h \right]$$

Where,

n_g	-	number of thermal units
P_i	-	active power generation at unit *i*
d_i , e_i , f_i	-	parameters estimated on the basis of unit emissions

X. COMBINED EMISSION AND ECONOMIC DISPATCH PROBLEMS:

A. Introduction

When we concentrate on reducing the pollution level, the fuel cost increases. However there are many methods to concentrate on minimizing the both. The modern operational strategies of the generating plants now include reduction of pollution level up to safe limit, in addition to minimum fuels cost strategy. This is known as Combined Emission and Economic dispatch.

B. Objective function

The objective function is given by

$$FC = \sum_{i=1}^{n_g} F_i(P_i)$$

$$EC = \sum_{i=1}^{n_g} E_i(P_i)$$

$$\phi = FC + \eta EC [Rs/h]$$

Where,

n_g	-	number of thermal units
P_i	-	active power generation at unit *i*
FC, EC	-	total fuel cost and total emission release
η	-	Price penalty factor

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C. Example Problem And Simulation Results

The efficiency of the proposed method has been demonstrated by solving the following problems. The corresponding results and parameter selection are also given.

IEEE 30 bus system with 6 generators

Fuel Cost Equations (Rs/ h):

$F_1 = 0.15247 P_1^2 + 38.53973 P_1 + 756.79886$

$F_2 = 0.10587 P_2^2 + 46.159 P_2 + 451.32513$

$F_3 = 0.02803 P_3^2 + 40.39655 P_3 + 1049.99770$

$F_4 = 0.03546 P_4^2 + 38.30553 P_4 + 1243.53110$

$F_5 = 0.02111 P_5^2 + 36.32782 P_5 + 1658.55960$

$F_6 = 0.01799 P_6^2 + 38.27041 P_6 + 1356.65920$

NO_x Emission Equations (kg/h):

$F_1 = 0.00419 P_1^2 + 0.32767 P_1 + 13.85932$

$F_2 = 0.00419 P_2^2 + 0.32767 P_2 + 13.85932$

$F_3 = 0.00683 P_3^2 – 0.54551 P_3 + 40.26690$

$F_4 = 0.00683 P_4^2 – 0.54551 P_4 + 40.26690$

$F_5 = 0.00461 P_5^2 – 0.514116 P_5 + 42.89553$

$F_6 = 0.00461 P_6^2 – 0.514116 P_6 + 42.89553$

TABLE 1: PARAMETER SELECTION

PARAMETER	CHOSEN VALUE
Population size	20
Number of generations	500
Crossover probability	0.5
Mutation Probability	0.01

TABLE 2: COMBINED ECONOMIC AND EMISSION DISPATCH (CEED) RESULTS

1) For Power Demand (P_D)= 900 MW; Price Penalty factor (h) = 47.822 Rs/kg

METHOD	FUEL COST Rs / hr	EMISSION Kg / hr	LOSSES P_L (MW)	TOTAL COST Kg / hr
Conventional Method	48567.900	701.428	35.230	82436.580
GA Method	48567.700	694.169	29.725	81764.500

2) For Power Demand (P_D) = 500 MW; Price Penalty factor (h) = 43.898 Rs/kg

METHOD	FUEL COST Rs / hr	EMISSION Kg / hr	LOSSES P_L (MW)	TOTAL COST Kg / hr
Conventional Method	27638.300	262.472	8.830	39159.500
GA Method	27692.100	263.370	10.172	39258.100

XI. CONCLUSION

In this paper the performance of the proposed method was tested for IEEE 30 bus system with 6 generators. The combined economic and emission dispatch problems have been solved by the proposed GA method and the results have been compared with the conventional method. The results proved that the proposed algorithm is capable of obtaining optimum results for the nonlinear optimization.

The performance of the genetic algorithm for solving combined economic and emission dispatch problem has been demonstrated.

A. A new algorithm called Genetic Algorithm has been explored.
B. From the comparison of results, it is proved that the algorithm is capable of identifying the near global optimum solution.
C. Like other conventional algorithms, it also has the capability to handle the equality and inequality constraints.
D. The proposed algorithm is suitable for solving non linear optimization problems.
E. From comparison of results of CEED, it is proved that GA is capable of giving better results compared to other algorithms.

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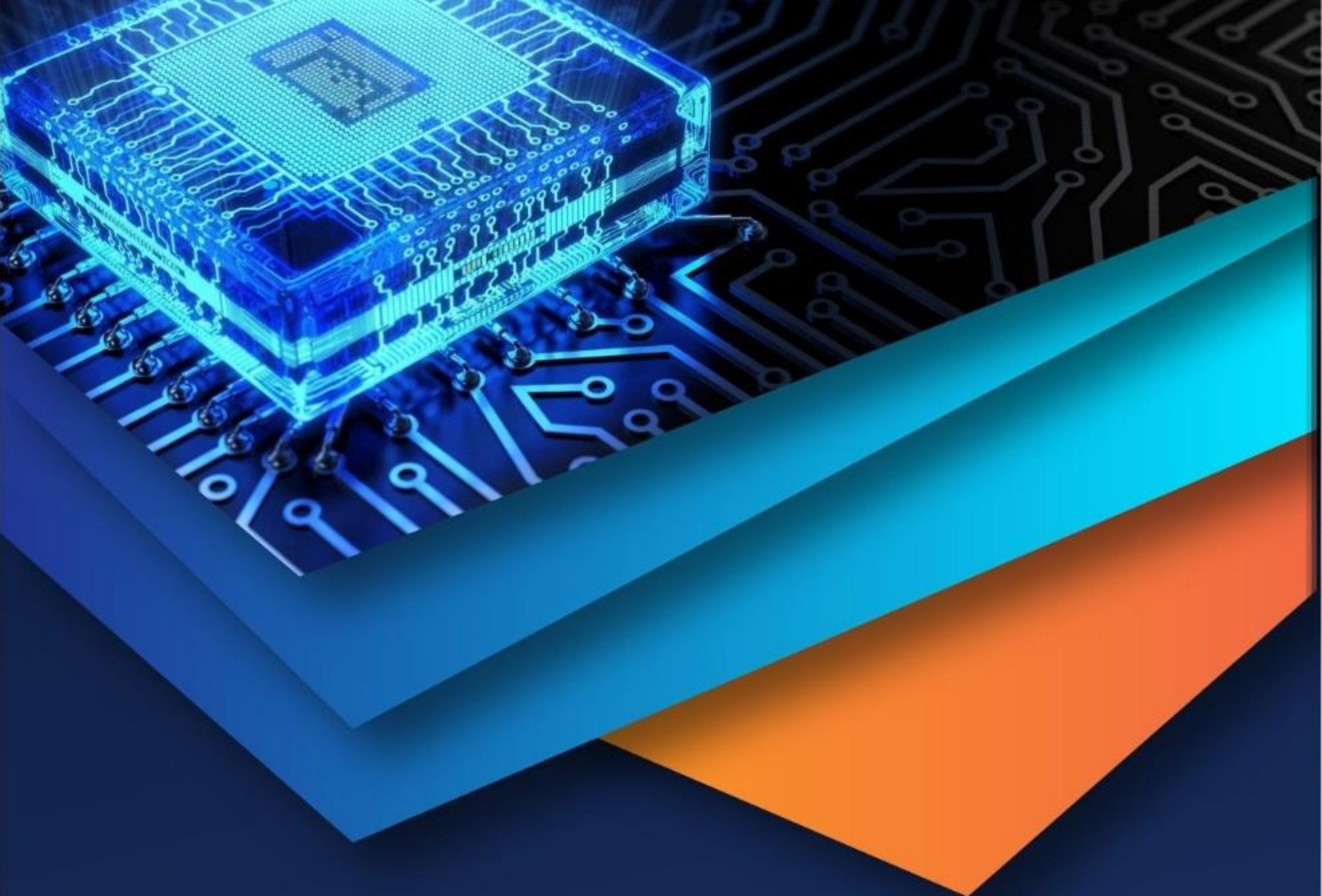

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