COMBINED ECONOMIC AND EMISSION DISPATCH USING PARTICLE SWARM OPTIMIZATION

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Abstract
By the use of fossil based fuels in generating stations creates more problems while considering the pollution created by the plants. At the present time, the extensive use of fossil based fuels in power generation units requires the concern of the environmental pollution. The traditional economic power dispatch cannot meet the environmental safety requirements, since it focus only on minimizing the total fuel cost of the system. The multi-objective optimization in electric power systems treats economic and emission act as competing objectives, to reach an optimal solution some reasonable trade off among objectives are require. The exact solution of economic dispatch is obtained only by considering those environmental impacts. So economic dispatch becomes combined environmental economic dispatch problem (CEED) and this problem is now bi-objective function with cost function and emission function as objective functions. An efficient and reliable Particle Swarm Optimization (PSO) algorithm based technique is used for solving the emission and economic dispatch problem. CEED is the online process for allocating the generation among the available generating unit to fulfill the load demand in such a way to minimize the total generation cost and satisfying the equality and inequality constraints. In literature many papers have used the particle swarm optimization to solve the economic load dispatch problem with emission constraint which is a population based optimization technique inspired by sociological behavior of bird flocking. CEED problem is formulated a nonlinear multi-objective function as objective function by considering both equality and inequality constraints. The multi-objective optimization in power systems treat economic and emission as conflicting objectives, to get an optimal solution. So in this paper, the power dispatch is formulated into a two objective optimization problem, which is to minimize the fuel cost as well as emission simultaneously. The suggested modifications have improved the accuracy, convergence rate, robustness and effectiveness of the algorithm, which has produced high-quality solutions for the CEED problem.

Keywords:
Combined Environmental Economic Dispatch (CEED), Electric Power Systems, Fuel Cost, Optimization, Particle Swarm Optimization (PSO) algorithm.

1. Introduction

In a power plant, allocating power generated by different units on an optimum economy basis with a commitment to meet the demand is necessary for achieving efficiency. However, the existing sources of energy production are not ecologically clean. Traditionally electric power systems are operated in such a way that the total fuel cost is minimized regardless of emissions produced. The harmful ecological effects caused by the emission can be reduced by adequate distribution of load between the units of power plant. In essence it is an optimization problem and its objective is to reduce the total generation cost of units, emissions such as CO2, SO2 and NOX caused by the operation of fossil-fueled thermal generation while satisfying constraints. The twin concerns of cost and Emission (to meet environmental regulations, Clean Air Act Amendments of 1990, enforced in recent years) cannot be addressed together. Invention of pollutant cleaning equipment, leads to minimize fuel cost and emission, alternative old fuel burners with more clean ones, and emission dispatching. The emission dispatching option is an attractive option, which is economic as well as emission effective. A balance has to be achieved with either of them getting more priority. Under the present environmental conditions, a compromise in cost with emphasis towards reduced emissions is the need of the hour. So it is a multi-objective Economic dispatch problem with environmental constraints.

In seeking the solution for the combined economic emission dispatch(CEED) problem the main aim is to operate a power system in such a way to supply all the loads at the minimum fuel cost of generation and environmental pollution caused by emission of toxic gases of fossil based thermal generating units. The solution technique which is applied to the CEED is particle swarm optimization (PSO) method. In electric power system operation, the objective is to achieve the most economical generation policy that could supply the local demands without violating constraints. Thermal stations, during power production, burn fossil fuels that generate toxic gases in their effluent and these become a source of pollution for the environment. The CEED calculation optimizes the static operating condition of a power generation-transmission system with security of quality of service.

One of the most recent meta-heuristic algorithms, the Particle Swarm Optimization (PSO), is a population based stochastic optimization technology by Eberhart and Kennedy in 1995, inspired by social behavior of bird flocking and fish schooling. It is used for optimization of continuous nonlinear functions. PSO is applied to different areas of power systems to minimize real power system losses.

The PSO technique is proposed to solve EED multi-objective problem by generating the Pareto optimal solution set that shows compromising solutions between each pair of the conflicting objective functions. Also, a multi-objective optimization problem consisting of four objectives is tackled using weighting method.

Table 1: Literature review of PSO methods.

Author(s) [References]	**Contributions**
Kennedy and R. Eberhart [1]	Introduced Particle Swarm Optimization (PSO), The original objective of their research was to graphically simulate the social behavior of bird flocks and fish schools.
Spens and Lee [2]	Solved the economic load dispatch under environmental restrictions in a multi-hour time horizon minimizing fuel consumption cost for SO2 and NOx.
Fan and Zhang [3]	Solved a cost minimization problem proposing a solution via quadratic programming, where environmental restrictions are modeled with linear inequalities.
Gent and Lamont [4]	Introduced the minimum emission dispatch where they developed a program for one-line stream unit dispatch, that result in minimizing NOx emission.
Dhillon et.al [5]	Formulated the multi-objective thermal power dispatch using non-commensurable objectives such as operating costs and minimal emission.
Song et.al [6]	Developed Genetic Algorithms (GAs) for EED, whose parameters are adaptively tuned by fuzzy logic controllers.

Venkatesh et al. [7]	Comprehensive comparison is done, regarding genetic algorithm, micro GA, evolutionary programming in solving EED.
Abido [8]	Used Strength Pareto Evolutionary Algorithm(SPEA) to solve EED problem.
Huang et al. [9]	Used MOCLPSO, as algorithm performing well in converging to the true Pareto Optimal front with fewer fitness functions evaluation for several test problems.
T.A.A Victoire [10]	MOCLPSO algorithm is applied to solve the EED optimization problem.
Bouktir et al. [11]	Presented a use of Reliable Particle Swarm Optimization (RPSO) method for solving efficiently the economic dispatch problem.
Gnanadass et al. [12]	Proposed a fast novel modified price penalty factor method to solve Combined Economic Emission Dispatch Problem (CEEDP).
Swarankar [13]	Reliable Particle Swarm Optimization (RPSO) method is applied for solving the OPF problem in the practical power system test case.
Coello [14]	Proposed MOPSO, which combines PSO with concept of the Pareto dominance to handle multi-objective optimization problem.
Miranda [15]	Proposed EPSO, in which EPSO combines PSO with evolutionary strategies of replication, mutation, reproduction, evaluation and selection.
H. Mori [16]	Proposed MOEPSO, In MOEPSO that may search various directions from one particle, replicated particles move to other solutions using mutated various gbests of the repository.
El-Keib et al. [17]	Studied a La Grangian relaxation method for identifying the optimal economic and environmental dispatching of thermal generating units.
Talaq et al. [18]	Presented the economic and environmental objectives by combining them linearly to form a single objective function using the weighting factors.
Yokoyama et al. [19]	Applied the artificial intelligence and the fuzzy satisfaction-maximizing to simultaneously consider both optimal fuel cost and optimal emission and then searched

	for a set of non-inferior solutions from the multiple objective functions.
Sen-Nien Yu and Wei-Hsuan Chung [20]	Used MPSO algorithm to determine the optimal solution that minimizes both the fuel cost and emission.
Ming-Tang Tsai [21]	Presented Improved Particle Swarm Optimization(IPSO) to solve the economic dispatch problems considering both fuel cost and environmental issue.
Hao Gao and Wenbo [22]	Proposed PSO with Moderate random search strategy(MRPSO) enhances the global search ability of the PSO.
Nagendra Singh [23]	Studied PSO with moderate random search technique (MRPSO) to solve the economic load dispatch with environmental emission as the constraints.
Jordan Radosavljević [24**]**	His study proposes a hybrid PSO and GSA (hybrid PSOGSA) algorithm to solve the CEED problem.
Manojkumar T. [25]	He proposes the use of Particle Swarm Optimization (PSO) to solve the multi-objective function which is a global searching technique.
Biswajit Purkayasha et al. [26]	He aims at non dominated solutions in considering the multi-objective optimization problem of economic and emission dispatch using Non-Dominated Sorting GA II.
Anurag Gupta et al. [27]	Used PSO on the combined economic and emission dispatch problem. It combines the two objectives into one using the price penalty function
M. R. Alrashidi et al. [28]	He proposed that, EED problem uses weighting functions on the double objective of emission and fuel cost.
B. Lokeshgupta et al. [29]	Proposed a combined model of multi objective dynamic economic and emission dispatch (MODEED) and demand side management (DSM) technique using multi objective particle swarm optimization (MOPSO) algorithm**.**
Sachin Soni [30]	Proposed a unique hybrid particle swarm optimization (HPSO) algorithm is used for the programming.
Niknam [31]	Tested a fuzzy adaptive PSO (FAPSO) combined with the Nelder–Mead (NM) simplex search.
Chaturvedi et al. [32]	Suggested a parameter automation strategy called self-organizing hierarchical PSO (SOH_PSO). In that method, the particle velocities were reinitialized**.**

Hosseinnezhad et al. [33]	Presented a species-based quantum particle swarm optimization (SQPSO) technique, in which particles were classified according to the found solutions and answers were explored in each iteration in-group form.
Selvakumar and Thanushkodi [34]	Introduced a new PSO (NPSO). In their method, a split-up in the cognitive behavior of the particles was performed.
Cao et al. [35]	Presented an enhanced particle swarm optimization (EPSO) technique with the ability to filter out unnecessary structural analyses in the optimization procedure.
Hamid Rezaie et al.[36]	Proposed advanced PSO (APSO) that incorporates some innovative modifications into the original PSO procedure. The results and statistical data demonstrate that these modifications significantly enhanced the accuracy and efficiency of PSO.

Generally, the heuristic methods like Particle Swarm Optimization techniques and their various modifications have shown marked improvement in the addressing of the economic dispatch problem as well as the combined economic and emission dispatch problem. From the above literature there shows a need in still improving the quality of solutions for the combined economic and emission dispatch problems, in terms of better convergence, lower losses, faster computation times, reduced fuel costs and reduced emissions. It is worthy of notice that hybrid methods yield superior solutions, either a heuristic and a traditional method or two heuristics.

1.1 Objective of this research

1. Study the multi-objective problem of the power system in terms of fuel cost and emission, where here the emission is primarily Nitrogen Oxide (NOx).
2. To combine the multi-objective problem into one objective using the weighting function method and cardinal priority ranking.
3. Study the Particle Swarm Optimization models.
4. To formulate an algorithm that hybridizes the advantages of optimization models and applies it to the multi-objective problem.

2. Optimal Load Dispatch Problem Formulation

The fundamental requirement of power system economic load dispatch is to generate, at the lowest possible cost, the adequate quantity of electricity to meet the demand. It is defined as the minimization of the combination of the power generation, which minimizes the total cost while satisfying the power balance relation. To meet the stringent quality requirements, accurate tools based on realistic models with faster solution speed and a high degree of reliability is required. To achieve higher reliability, improved security, and less environmental impact, utilities are implementing tighter control on operation of their facilities. Hence the combined economic emission dispatch (CEED) option is an attractive short term alternative in which the emission in addition to the fuel cost objective is to be minimized. Minimum emission dispatching may be imposed by government and regulatory agencies of developing countries also in the near future to control and reduce air pollution. These have brought about the necessity of greater sophistication in power system planning, operation and control. The problem of economic dispatch can be formulated as minimization of the cost function subjected to the equality and inequality constraints.

2.1 Economic Dispatch

Economic Dispatch (ED) optimization problem is one of the most important issues which must be taken into consideration in power systems. The problem of ED in power systems is to plan the power output for each devoted generator unit in such a way that the operating cost is minimized and simultaneously, matching load demand, power operating limits and maintaining stability. Based on convention, electrical power systems are operated based on minimizing operational cost while maintaining system constraints. The total generator operating cost includes fuel, labor, supplies and maintenance costs. For simplicity we consider fuel cost as the only variable cost since generally the costs of labor, supplies and maintenance are fixed percentages of the fuel cost. The fuel cost is meaningful in the case of thermal and nuclear plants, but nuclear plants are operated at constant output levels and for hydro stations where the energy cost is apparently free, the operating cost is not that meaningful. The majority of generators are nuclear, hydro and fossil. The figure below is a simple model of a fossil fuel plant. The power output of the fossil fuel plant is increased sequentially by opening a set of valves at the inlet to its steam turbine. The throttling losses in a valve are as large as just when it is opened and small when it is fully opened. Figure 1 shows the model of fossil fuel.

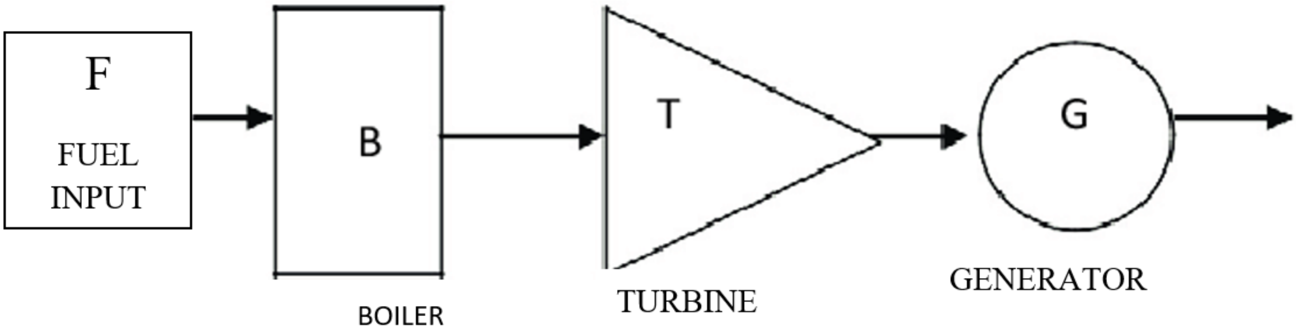

Figure 1: Simple Model of Fossil Fuel

Problem Formulation for Economic Dispatch on a Bus Bar

The minimum fuel cost of i_{th} unit is formulated as:

$F_c(P_i) = a_i(P_i)^2 + b_iP_i + c_i + e_i.\sin(f_i * (P_{gi(min)}. - P_{gi}))\ \$/h$

Cost of all units can be characterized as:

$E_m(P_i) = \alpha iPi\ 2 + \beta_iP_i + \gamma_i + \varepsilon_i \times e^{(\delta i \times Pgi)}$ kg/ h

Subject to:

a) Equality constraints

$((\sum_{i=1}^{n} P_{gi}) - P_L - P_D) = 0$

Where P_{gi} is generated power by i_{th} unit, P_L indicates the power loss, P_D is power demand and n is all total number of generating units.

The power losses are evaluated as:

$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_{gi}B_{ij}P_j$

where B is loss coefficient matrix.

b) Inequality constraints:

$P_{gimin} \leq P_{gi} \leq P_{gimax}$

where P_{gimin}. and P_{gimin} are minimum and maximum generating power limits of i_{th} generating units.

2.2 Emission Dispatch

The primary objective of this problem is to determine the most economic loadings of the generators such that the load demands of the generation can be met and the operation constraints of the generators are satisfied. In addition, the total emissions need to satisfy the allowable emission limit. The generation of electricity from fossil fuel releases several contaminants, such as Sulfur Oxides, Nitrogen Oxides and Carbon Dioxide, into the atmosphere. The two primary power plant emissions from a dispatching perspective are sulfur oxides (SO_x) and nitrogen oxides (NO_x). In the power plant, the sulfur enters the boiler as a part of the fuel. During the combustion process, some of the sulfur unites with oxygen from the fuel and combustion air to form SO_x. The remaining sulfur becomes a part of the bottom ash in the boiler. If stack gas cleans up equipment is present, most of the is SO_x removed. The remaining SO_x exits the stack as an emission. Fuel blending, fuel switching and scrubbers are the primary methods for reducing the amount of SO_x emitted. NO_x emissions are more complex. There are two sources of nitrogen that combine with oxygen from the fuel and the combustion air to produce NO_x. The first source is nitrogen in the air that produces an emission called thermal NO_x. The second source is nitrogen in the fuel that produces an emission called fuel NO_x. The total NO_x produced during combustion is the sum of the thermal NO_x and fuel NO_x. In coal, there is no apparent correlation between the amount of fuel-bound nitrogen and the fuel NO_x produced.

Problem Formulation for Emission Dispatch on a Bus Bar

The emission from a generating units should be within permitted limit. The emission constraint can likewise be taken as.

$E_m (P_i) = \alpha i P i\ 2 + \beta_i P_i + \gamma_i + \varepsilon_i \times e^{(\delta i \times Pgi)}$ kg/ h

$E_m(P_i) \leq \alpha E_{max}$

$\alpha \leq 1$

where α is emission limit factor. E_{max} is the maximum emission limit at minimum fuel cost and $E_m(P_i)$ is the total emissions from thermal generating units.

2.3 Combined Economic and Emission Dispatch

The Combined Economic emission load dispatch(CEED) problem is one of the fundamental issue in power system operation. The CEED has been usually considered as the minimization of an objective function representing the generation cost and the transmission loss. The constraints involved are the physical laws governing the power generation-transmission systems and the operating limitations of the equipment. CEED is the online process for allocating the generation among the available generating unit to fulfill the load demand in such a way to minimize the total generation cost and satisfying the equality and inequality constraints. In literature many papers have used the particle swarm optimization to solve the economic load dispatch problem with emission constraint which is a population based optimization technique inspired by sociological behavior of bird flocking. This problem is formulated a nonlinear multi-objective function as objective function by considering both equality and inequality constraints. The multi-objective optimization in power systems treat economic and emission as conflicting objectives, to get an optimal solution. So in this paper, the power dispatch is formulated into a two objective optimization problem, which is to minimize the fuel cost as well as emission simultaneously.

Problem Formulation for Economic and Emission Dispatch

Emission constrained Economic Dispatch problem is to decide the generated power of all on-line generating units which limits the all total fuel cost as well as limiting the environmental constrains of the system, while fulfilling equality and inequality constraints.

The CEED problem can be defined as:

Min $F_T = \sum_{i=1}^{n}(F_c(P_i) + E_m(P_i))$

Where F_t is combined objective function to be limited $F_c(P)_i$ indicates fuel cost of i_{th} generating unit and $E_m (P_i)$ indicates minimizing emission constraints of i_{th} generating unit.

The combined economic emission dispatch problem is formulated by combining both emission and fuel cost functions by actualizing penalty factor h_i

Min $F_c = (\sum_{i=0}^{n}(a_i (P_i)^2 + b_iP_i + c_i + e_i \times \sin(f_i \times (P_{gi(min)} . - P_{gi}) + h_i(\alpha_i(P_i)^2 + \beta_iP_i + \gamma_i + \varepsilon_i \times e^{(\delta i \times Pgi)})$ \$/h

The power generated by solar plant is evaluated as:

$P_{gs} = P_r \{1 + (T_{ref} - T_{amb}) \times \alpha\} \times (S_i /1000)$

where P_r is its rated power, T_{ref} is the reference temperature, T_{amb} is the ambient temperature, α is temperature coefficient and S_i is the incident solar radiation.

The solar share is calculated form generating units taking part in the dispatch:

$E_{ss}=\sum_{j=1}^{m} P_{gs\ j}$

where $P_{gs\,j}$ is power available from j[th] solar plant in operating zone.

At the point, when we combine the single objective function of solar share and total available solar power to tackle the most extreme advantage of solar availability, considering the cost minimization, formulation of the combined objective function is as below:

Min $F_T = F_i(P_i) + E_i(P_i)$

Subject to:

$P_D + P_L - \sum_{i=1}^{n} P_{gi} - \sum_{j=1}^{m} P_{gs\,j} = 0$

$P_{gimin} \leq P_{gi} \leq P_{gimax}$

3 CEED Using Particle Swarm Optimization (PSO) Technique

The PSO technique is proposed to solve EED multi-objective problem by generating the Pareto optimal solution set that shows compromising solutions between each pair of the conflicting objective functions. Also, a multi-objective optimization problem consisting of four objectives is tackled using weighting method.

3.1 Particle Swarm Optimization

Particle Swarm Optimization (PSO) was first introduced by Kennedy and Eberhart in 1995.PSO is based on observation of foraging behaviors of birds. When birds forage, they communicate information to find targets efficiently. Individuals provide messages to the population, thus influence the group behavior, which is a normal social phenomenon in nature. If the message provided by an individual is regarded as local solution, the foraging process could be regarded as solving the global optimal solution. PSO has been successfully applied in the different engineering problems. PSO is similar to random search methods, but it does not contain complicated mechanisms such as crossover or mutation. PSO generates a set of initial solution, known as particles, through the initialization mechanism, and then searches the optimal value through iteration evolution. More importantly, every particle has a memory capacity, and can provide one-way message to the population. The adjustment towards personal best position "pbest" and global best position "gbest" by the particle swarm optimizer is conceptually similar to the crossover operation utilized be genetic algorithm. Thus, the search process of PSO is the process of following current optimal solution. PSO simulates the foraging process. For example, if there is food somewhere, and its location is unknown to the population, but the distance is known. Then, the simplest method to find the food is to search the peripheral regions of the birds that are closest to the food. PSO can have several solutions at the same time. Each solution is called a particle, and particles have a cooperative relationship for sharing messages. Through specific equations, each particle adjusts its position and determines the search direction according to its search memory and that of others. In other words, it tries to reach compatibility between local search and global search. The global optimum is found out after iteration evolution. The search memory of particle is the objective value and the optimum position searched by the particle.

3.2 Formulation of Particle Swarm Optimization

In the search space, the velocity and position influence the search behavior of PSO. The number of particle is set as i = 1,2, ..., PS, PS (Population Size) total amount of particles.

The particles are manipulated according to the following equations.

$v_i^{(r+1)} = w.\, v_i^{(t)} + c1\,.\,r1\,.(\,x_{gbest}^{(t)} - x_i^{(t)}) + c2 * r2 *(x_{ipbest}^{(t)} - x_i^{(t)})$

$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)}$

Where,

t: pointer of iterations (generations).

w: inertia weight factor.

c_1, c_2: acceleration constant.

r_1, r_2: uniform random value in the range (0, 1). (t)

$v_i^{(t)}$: Velocity of particle i at iteration t.
$x_i^{(t)}$: current position of particle at iteration t.
$x_{ipbest}^{(t)}$: previous best position of particle t at iteration t.
$x_{ipbest}^{(t)}$: best position among all individuals in the population At iteration t.
$v_i^{(t+1)}$: new velocity of particle i.
$x_i^{(t+1)}$: new position of particle i.
Inertia weight is modified after each iteration and is expressed as a modified equation:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter$$

Where, w_{max} is the maximum value of inertia weight.
w_{min} is minimum value of inertia weight.
$iter_{max}$ is maximum number of iterations.

3.3 Advantages of PSO over other optimization techniques

PSO is a population-based evolutionary technique that has many key advantages over other optimization techniques like:

- It is a derivative-free algorithm unlike many conventional techniques.
- It has the flexibility to be integrated with other optimization techniques to form a hybrid tool.
- It is less sensitive to the nature of the objective function, i.e. convexity or continuity.
- It has less parameters to adjust unlike many other competing evolutionary techniques.
- It has the ability to escape local minima.
- It is easy to implement and program with basic mathematical and logic operations.
- It can handle objective functions with stochastic nature.
- It does not require a good initial solution to guarantee its convergence.

3.4 Steps of PSO algorithm for dispatch problem

The PSO algorithm for dispatch problem is stepped as follows:
Step 1: The particles are randomly generated between the maximum and minimum operating limits of the generators.
Step 2: The particle velocities are generated randomly.
Step 3: Objective function values of the particles are evaluated. Penalties are given for violations of demand constraint (2). These values are set the pbest value of the particles.
Step 4: The best value among all the pbest values (gbest) is identified.
Step 5: New velocities for the particles are calculated using (1).
Step 6: The positions for each particle are updated using (2)
Step 7: New objective function values are calculated for the new positions of the particles. If the new value is better than the previous pbest, the new value is set to pbest. If the stopping criterion is met, the positions of particles represent the optimal solution. Otherwise the procedure is repeated from step 4.

Figure 2 illustrates the flow chart of particle swarm optimization (PSO) algorithm.

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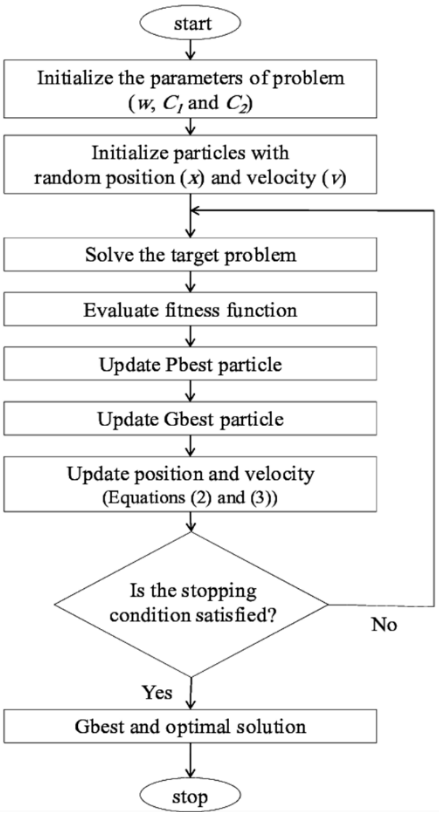

Figure 2: Flow Chart of Particle Swarm Optimization

4. Conclusion

This paper introduces a Particle Swarm Optimization algorithm to solve the economic power dispatch of power system with pollution control. The fuel cost and emission are combined in a single function with a difference weighting factor. The main advantage of PSO over other modern heuristics is modeling flexibility, sure and fast convergence, less computational time than other heuristic methods. PSO requires only a few parameters to be tuned, which makes it attractive from an implementation viewpoint. The feasibility of the proposed algorithm is demonstrated on an IEEE 30-bus system. The results show that the proposed algorithm is applicable and effective in the solution of OPF problems that consider nonlinear characteristics of power systems with different objective functions. PSO can generate an efficiently high quality solution and with more stable convergence characteristics than Genetic Algorithm.

In literature survey so many conventional methods are proposed for the solution of combined economic and emission dispatch (CEED) problem. In all above mentioned papers, we are only considering one loading condition for a given system. All these methods can’t find the global optimal solution but gets reasonable solution which is nearly global optimal. In order to obtain Pareto Optimal solution of environmental/economic dispatch problem, a PSO algorithm was developed solve a constrained economic and emission dispatch problem. The PSO algorithm was mainly used to determine the optimal lambda solution and hence power generation of each unit that was submitted to operation at the specific period, thus minimizing the total emission and total generation cost. By using PSO we can come into conclusion that it is the ability to provide accurate and feasible solutions within reasonable computation period.

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