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# Environmental/economic power dispatch using a fuzzified multi-objective particle swarm optimization algorithm

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**Abstract**

The environmental issues that arise from the pollutant emissions produced by fossil-fueled electric power plants have become a matter of concern more recently. The conventional economic power dispatch cannot meet the environmental protection requirements, since it only considers minimizing the total fuel cost. The multi-objective generation dispatch in electric power systems treats economic and emission impact as competing objectives, which requires some reasonable tradeoff among objectives to reach an optimal solution. In this paper, a fuzzified multi-objective particle swarm optimization (FMOPSO) algorithm is proposed and implemented to dispatch the electric power considering both economic and environmental issues. The effectiveness of the proposed approach is demonstrated by comparing its performance with other approaches including weighted aggregation (WA) and evolutionary multi-objective optimization algorithms. All the simulations are conducted based on a typical test power system.


*Keywords:* Multi-objective optimization; Particle swarm optimization; Environmental/economic power dispatch; Local/global search; Constraint satisfaction

## 1. Introduction

In recent years, with an increasing awareness of the environmental pollution caused by thermal power plants, limiting emission of pollutants is becoming a crucial issue in economic power dispatch. Power plants using fossil fuels as their major energy source generate particulates and gaseous pollutants including carbon dioxide, oxides of sulphur, and oxides of nitrogen. This may violate the ever-tighter environmental protection regulation since the excessive amount of emissions pollutants inevitably causes detrimental ecological effects. Emissions may be reduced by utilizing fuels with lower emission. Fuel switching is dependant on the price and availability of low-pollution fuel. Furthermore, switching from one fuel to another has many implications such as job losses in coal mining areas. Thus, it is an expensive solution. As an alternative, environmental/economic dispatch (EED) is proposed as a viable solution since it is able to reduce the pollutant emissions with lower generation cost.

Most previous economic power dispatch dealt with the case of each generating unit having a single cost function. However, certain practical thermal units use different fuels like coal, natural gas and oil, which have different heat contents. These units are faced with the problem of deciding the most economical fuel to burn. The multiple fuel options lead to piecewise quadratic cost functions (PQCF). Lin and Viviani [20] proposed a hierarchical approach for economic dispatch problems with PQCF. A linear programming based optimization procedure was proposed in [9], where one objective is considered at a time. Rifaat [23] developed the model for economic dispatch of combined cycle cogeneration units considering environmental constraints and used nonlinear programming technique to handle it. Park et al. [22] employed Hopfield neural networks to treat the economic dispatch problems with PQCF. A revised adaptive Hopfield neural network scheme was developed to deal with this problem by Lee et al. [19]. Jayabarathi et al. [14] applied evolutionary programming techniques to solve this type of problems. Later, optimization models were formulated to minimize or maximize a single scalar objective function. For instance, Gaing [11] deployed particle swarm optimization (PSO) to implement the economic power dispatch considering generator constraints. However, it is more natural for the analysts to consider multiple objectives simultaneously. The power system can also operate most economically and incur less environmental problems when optimized with respect to several criteria under a bunch

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of necessary constraints. Very often, the multi-objective problems are solved by finding non-inferior (i.e., Pareto-optimal, non-dominated) solutions. Prom the qualitative perspective, a non-inferior solution in a multi-objective problem is one where any improvement of one objective function can be attained only at the expense of another. The commonly used methods of producing these non-inferior solutions are the ∈-constraint and weighted minimax methods. A wide range of new techniques is being used these years to tackle the EED problem in a more effective fashion. For instance, Dhillon et al. [8] handled EED using a stochastic approach considering various uncertainties. Song et al. [27] developed genetic algorithms (GAs) for EED, whose parameters are adaptively tuned by fuzzy logic controllers. Roa-Sepulveda and Herrera [24] dealt with the EED problem using an improved decision tree technique. A comprehensive comparison study regarding genetic algorithm, micro-GA, and evolutionary programming in solving EED was reported by Venkatesh et al. [30]. Abido [1–3] used multi-objective evolutionary algorithms to dispatch the electric power. Ah King [4] dealt with EED using both deterministic and stochastic evolutionary approaches. Neural-fuzzy techniques were used in [13] for multi-objective generation dispatch.

It can be seen that recently the meta-heuristic optimization methods have been significantly used in EED primarily due to their nice feature of population-based search. Particle swarm optimization is such a technique. We adopt PSO to handle the complexity and nonlinearity of the problem. PSO has several key advantages over other existing optimization techniques in terms of simplicity, convergence speed, and robustness [5,18].

- PSO is easy to implement in computer simulations using basic mathematical and logic operations, since its working mechanism only involves two fundamental updating rules. PSO also has fewer operators to adjust in the implementation, and it can be flexibly combined with other optimization techniques to build a hybrid algorithm.
- The mechanism of PSO facilitates a better convergence performance than some other optimization procedures like genetic algorithms, which have computationally expensive evolutionary operations such as crossover and mutation.
- Unlike the traditional optimization algorithms, PSO is a derivative-free algorithm and thus it is especially effective in dealing with complex and nonlinear problems. PSO is more robust to deal with such problems, since it is less sensitive to the nature of the objective function in terms of convexity and continuity, and the inner working of PSO helps to escape local minima. The robustness of PSO can also be reflected by its less sensitivity to the optimizer parameters as well as the initial solutions to start its iteration process. Furthermore, PSO avoids the so-called curse of dimensionality that the dynamic programming (DP) suffers in handling practical economic dispatch problems.

Meanwhile, PSO has also certain limitations that should be taken care of in dealing with economic dispatch problems. It still has some dependency on initial points, and the most effective combination of different parameters may need some time to tune. Also the final outputs have some stochastic characteristic. PSO is being used in diverse optimization problems. However, it was seldom used in multi-objective optimization problems (MOPs). In this paper, a novel fuzzified multi-objective particle swarm optimization (FMOPSO) algorithm is proposed to deal with the environmental/economic dispatch problem. The novelty of the developed algorithm can be demonstrated by the development of several distribution preservation mechanisms for dealing with multi-objective optimization case. The remainder of the paper is organized as follows. Section 2 formulates the target EED problem including its multiple objectives as well as design constraints. Section 3 presents the inner working of particle swarm optimization algorithms. The major concepts in multi-objective optimization problem are introduced in Section 4. The proposed FMOPSO algorithm is discussed in detail in Section 5. The simulation results as well as evaluation work are presented in Section 6. Finally, conclusion is given and future research directions are suggested.

## 2. Problem statement

The typical optimal environmental/economic power dispatch problem can be formulated as a bi-criteria optimization model. The two conflicting objectives, i.e., fuel cost and pollutants emission, should be minimized simultaneously while fulfilling certain system constraints. This problem is formulated in this section.

### *2.1. Problem objectives*

- Objective 1: Minimization of fuel cost

  The generators cost curves are represented by quadratic functions with sine components. The superimposed sine components represent the rippling effects produced by the steam admission valve openings [3]. The total $/h fuel cost $F(P_G)$ can be represented as follows:

$$F(P_G) = \sum_{i=1}^{M} a_i + b_i P_{Gi} + c_i P_{Gi}^2 + |d_i \sin[e_i(P_{Gi}^{\min} - P_{Gi})]| \tag{2.1}$$

  where $M$ is the number of generators committed to the operating system, $a_i$, $b_i$, $c_i$, $d_i$, $e_i$ are the cost coefficients of the $i$-th generator, and $P_{Gi}$ is the real power output of the $i$th generator. $P_G$ is the vector of real power outputs of generators and defined as

$$P_G = [P_{G1}, P_{G2}, \ldots, P_{GM}] \tag{2.2}$$

- Objective 2: Minimization of pollutants emission

  The most important emissions considered in the power generation industry due to their effects on the environment are sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$). These emissions can be modeled through functions that associate emissions with power production for each unit. Sulfur dioxide emissions are dependent on fuel consumption and they take the same form as the fuel cost functions used for economic dispatch. $NO_x$ emissions are more difficult to model since they come from different sources and their production is associated with several factors such as boiler temperature and