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Solution to scalarized environmental economic power dispatch problem by using genetic algorithm

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ABSTRACT

Nowadays, the widespread use of fossil based fuels in power generation units requires the consideration of the environmental pollution. Therefore, in this study, the solution of scalarized environmental economic power dispatch problem in which the environmental pollution has been taken into consideration has been analyzed by using genetic algorithm (GA). In order to turn the environmental economic power dispatch problem into the single objective optimization problem, the conic scalarization method (CSM) has been used. Also, weighted sum method (WSM) has been utilized in the scalarization of the same problem for comparison with CSM. The solution algorithm is tested for the electric power system of thermal units which has been solved by different methods in the literature. The best solution values that give minimum total fuel cost and minimum total emission values have been obtained (Pareto optimal values) for different weight values under electric constraints via CSM and WSM. The obtained Pareto optimal values for different scalarization methods have been compared with each other.

1. Introduction

In an electric power system, traditional economic power dispatch problem is to find the optimal power outputs for all generating units which will minimize the total thermal cost rate. Power outputs for all generating units should also satisfy the electric constraints in the considered electric power system [1–3].

Recently, environmental pollution created by some type of thermal units has become an important issue. Fossil fuel burning thermal units release several contaminants such as carbon dioxide, sulfur dioxide, nitrogen oxide and ash. Increase of those contaminants in large amounts can result in some deadly environmental effects such as global warming [4–6].

The solution obtained from a traditional economic dispatch cannot be taken as the best one since the environmental criteria are not taken into consideration in a traditional economic dispatch calculation. In order to have a cleaner environment, the amount of emission, produced by the thermal units, must be decreased. This can be done in different ways such as using fuels with lower sulfur content, utilizing equipments that decrease the carbon dioxide, sulfur dioxide, nitrogen oxide and ash emission of the generating unit or using new dispatch techniques that consider the above emissions. The main idea in the new dispatch techniques is based on employing more generation units that give less emission in order to reduce the amount of total emission [4,5].

In some optimization problems, there may be more than one objective function to be optimized. None of these objectives can be comparable with the others. Generally, in that type of optimization problems, there is no a unique solution, but a set of solutions. If all objectives are taken into consideration, none of the solutions in the solution set can be taken as the best one. These types of solutions are named as Pareto optimal solutions [7].

The problem can be considered as a multi objective optimization problem when both cost rate function and emission rate function are to be minimized. In literature, two different approaches are used to solve multi objective optimization problems. One of those approaches is to apply methods, which are able to solve multi objective optimization problems, directly. The other approach is to transform multi objective optimization problem into a single objective optimization problem and then apply appropriate method to solve single objective optimization problem. Transforming multi objective optimization problem into a single objective optimization problem by using an appropriate conversion is called *scalarization*. Some of the scalarization methods are the weighted sum (WSM), the ε-constraining, the elastic constraining, the Benson scalarization, the compromise programming, the conic scalarization (CSM) and the goal programming [8–11].

Some of the directly applied methods for solving multi objective optimization problems in literature which are genetic (or modified genetic) algorithm, particle swarm optimization method, differential evaluation method, chaotic ant swarm optimization method and chaotic particle swarm optimization method are shown in [2,12,13,3,6,14,15], respectively. First order gradient method, genetic algorithm, mathematical programming method which are

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Nomenclature

$TFCR$	total fuel cost rate, ($/h)
TER	total NO_x emission rate, (ton/h)
$CTFCR$	chosen total fuel cost rate ($/h)
$CTER$	chosen total emission rate (ton/h)
$P_{G,n}$	active generation of the nth thermal unit, (MW)
$P_{G,n}^{sol.}$	solution point active generation of the nth thermal unit, (MW)
$Q_{G,1}^{sol.}$	solution point reactive generation of the unit connected to the reference bus, (MVAr)
$F_n(P_{G,n})$	fuel cost rate of the nth thermal unit, ($/h)
$E_n(P_{G,n})$	NO_x emission rate of the nth thermal unit, (ton/h)
γ	scaling factor
w	weight factor, $(0 \leqslant w \leqslant 1)$
β	the vertex angle of a cone, $\{0 \leqslant \beta < \min[w,(1-w)]\}$
P_{load}, P_{loss}	total system active load and loss respectively, (MW)
$P_{G,n}^{\min}$, $P_{G,n}^{\max}$	lower and upper active generation limits of the nth thermal unit respectively, (MW)
N_G	set containing all generating units in a given power system

applied after multi objective optimization problem has been converted into single objective optimization problem via *WSM*, are shown in [16–19], respectively. Fuzzified multi objective particle swarm optimization algorithm, multi objective evolutionary algorithms, modified NGSA-II algorithm, fuzzy based bacterial foraging algorithm and gravitational search algorithm which are applied both directly to multi objective optimization problems and to scalarized multi objective optimization problems, are explained in [4,20–23], respectively. The solution of the problem by scalarization through a combination of WSM with the ϵ-constraining method appear in [24]. In Ref. [5], a summary of environmental economic dispatch algorithms is also given.

In this study, the environmental economic power dispatch optimization problem is converted into a single objective optimization problem by CSM and WSM; GA is applied for the solution. GA can attain a general optimum without getting stuck in local optimums by conducting a search with many variables across an immense range for the solution of optimization problems. Therefore GA method is preferred for the solution of environmental economic power dispatch problem.

2. Problem formulation

The solution to an environmental economic power dispatch problem gives active power generations for all generation units, which minimize the total fuel cost rate and total NO_x emission rate functions together. The solution also satisfies all possible electric constraints.

The fuel cost rate (cost per hour) functions of the thermal units in the considered electric power system are taken as follows:

$$F_n(P_{G,n}) = a_n + b_n P_{G,n} + c_n P_{G,n}^2, \ (\$/\text{h}) \quad (1)$$

The NO_x emission rate functions of the thermal units in the considered electric power system are also taken as,

$$E_n(P_{G,n}) = d_n + e_n P_{G,n} + f_n P_{G,n}^2 + g_n \ exp(h_n P_{G,n}), \ (\text{ton/h}) \quad (2)$$

The unit of $(P_{G,n})$ is accepted as MW in Eqs. (1) and (2). The power balance constraint in the lossy system is accepted as follows:

$$\sum_{n \in N_G} P_{G,n} - P_{load} - P_{loss} = 0 \quad (3)$$

The active power generation limits of the thermal units are given as below:

$$P_{G,n}^{min} \leqslant P_{G,n} \leqslant P_{G,n}^{max}, \ (n \in N_G) \quad (4)$$

In this study, scalarization by means of CSM is employed in order to solve the two objective optimization problem. CSM which has been developed by Gasimov, converts objective functions into a single function by combining such functions without imposing any constraining conditions upon objective functions and constraints. This scalarization technique uses support cones for the determination of Pareto efficient values.

In order to explain the CSM briefly, the following definitions should be given [8–11].

Assume $R_+^2 = \{(y_1, y_2) \in R^2 | y_1 \geqslant 0, \ y_2 \geqslant 0\}$;

Definition 1. Let S be a non-empty subset of R^2.

(a) If $(\{s\} - R_+^2) \cap S = \{s\}$, an element $s \in S$, being a Pareto minimal element of the set S, is written as $s \in min(S)$.
(b) If s is a Pareto minimal element of the set S, element $s \in S$ is properly minimal element of the set S (according to Benson) and is written as $s \in p - min(S)$. The zero element of R^2 is a Pareto minimal element of $cl(cone(S + R_+^2 - \{s\}))$. Here, cl denotes the closure of the set and $cone(S) = \{\lambda s | \lambda \geqslant 0 \text{ and } s \in S\}$.

Let two objectives optimization problem be defined as in Eq. (5), where X is a set of feasible solutions.

$$min[F_1(x), F_2(x)], \ x \in X \quad (5)$$

Let $F(x) = [F_1(x), F_2(x)]$ and let $F(X)$ be the image of X.

Definition 2. If $F(\bar{x}) \in min[F(X)]$, $\bar{x} \in X$ is called the Pareto efficient solution of the problem in Eq. (5). If $F(\bar{x}) \in p - min[F(X)]$, $\bar{x} \in X$ is called the proper efficient solution (according to Benson) of the problem in Eq. (5).

Let W be defined as:

$$W = \{(\beta, w) \in R \times R^2 | 0 \leqslant \beta < min(w_1, w_2), \ w_1 > 0, \ w_2 > 0\} \quad (6)$$

Theorem 1. *Suppose that, for some $(\beta, w) \in W$, an element $\bar{x} \in X$ is an optimal solution of the scalar minimization problem shown below.*

$$min\left[\beta \sum_{i=1}^{2} |F_i(x)| + \sum_{i=1}^{2} w_i F_i(x)\right], \ x \in X \quad (7)$$

In that case, element $\bar{x} \in X$ is a proper efficient solution of the problem defined in Eq. (5).

Theorem 2. *Assume that element $\bar{x} \in X$ is proper efficient solution of the problem defined in* Eq. (5). *Thus, $(\beta, w_1, w_2) \in W$ exists and element $\bar{x} \in X$ is an optimal solution for the scalar minimization problem below.*