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A multi-objective framework for multi-area economic emission dispatch

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ABSTRACT

Economic dispatch seeks for the most economical combination of generation units in power system while satisfying bunch of physical and operational constraints. Finding the most economical generation strategy in power markets with several generation zones is crucial for power system operation. Conventional economic dispatch models cannot find the most economical generation schedule in power system with different generation zones. Moreover, the most economical schedule of generation cannot satisfy the environmental expectations. Therefore, compromising between generation cost and environmental issues is unavoidable. In this connection, total emission produces by generation units is taken into consideration as an objective function in concert with generation cost function. Furthermore, different operational constraints including valve-point effect, prohibited operating zones and multi-fuel operation are considered to make the proposed approach more realistic. Considering all these restrictions necessitate solving the proposed problem, i.e. multi-objective multi-area economic dispatch problem, by a reliable and strong optimization algorithm. In this regard, a hybrid evolutionary algorithm based on the shuffle frog leaping algorithm and the particle swarm optimization is proposed to solve the proposed problem. Effectiveness of the proposed hybrid algorithm is verified on different test systems.

1. Introduction

The conventional Single-Area Economic Dispatch (SAED) has been employed for decades to obtain the most economical combination of generator outputs [1]. Areas of individual power systems are interconnected to operate with maximum reliability, reserve sharing, higher level of stability, and less generation cost than operated as isolated area [2]. Therefore, the SAED cannot be a suitable tool to obtain the most economical combination in the multi-area environment because there are bunch of limits on power flow between different areas over Tie-lines in which the SAED doesn't have any strategy to handle those restrictions. In this connection, Multi-Area Economic Dispatch (MAED) was presented to consider all Tie-line constraints and observe different generation and load patterns for different areas in order to obtain the most economical generation combination in multi-area power systems. The MAED is capable of computing the best generation combination in each area as well as obtaining the best power flows between different areas while satisfying different constraints, in order to optimize a specific objective function. The major goal of investigating MAED problem is preparing an online framework available to power systems operators who have to run the problem expeditiously in a wide variety of power systems with numerous power plants. In other words the MAED can determine the transferred power between different zones by optimizing the total cost or other objectives, individually or simultaneously, over the entire system while satisfying various constraints. Indeed, in multi-area power networks the total generation cost can be decreased by receiving active power from other areas which have more economical power plants. Under such circumstances, any fitness function, like the total

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fuel cost depends on diverse agreements in individual areas such as the Tie-line constraints, the policies adjusted by utilities, the price of power, power demands, etc.

Most studies on the MAED investigate the problem from economic point of view while solving the MAED problem just for minimizing the operation cost cannot take care of other issues in power systems such as environmental effect which is becoming a grave concern. Over the past decade, the US environmental protection agency forces generation companies to generate their required power not just at the minimum cost but also at the minimum pollution level. To ameliorate this condition, the MAED should be investigated as a Multi-Objective Optimization Problem (MOOP) that covers different objectives simultaneously. One objective that can be considered in the MAED is the emission objective function which directly takes care of environmental issues. Toward this end, the proposed approach investigates the MAED as a MOOP.

This study investigates the Multi-objective Multi-Area Economic Dispatch (MOMAED) with different operational constraints including Valve-Point Effect (VPE), Prohibited Operating Zones (POZs), and Multi-Fuel Operation (MFO). Each generation unit has several valves to control the output power. The first opening of these valves cause losses increase results in ripple in cost functions known as valve point effect. Another restriction that has taken into account in this study is POZs which are disjoints in the operating region spectrum.

Operating in POZs is not possible or recommended because the proliferation of vibrations in the shaft bearing may occur leading to instability of unit' operation. To avoid these instabilities, the concept of POZs was developed [3–6].

A less studied and important practical characteristic of generation units is multiple fuel types of generation units which makes the generation cost a piecewise function.

The MOMAED problem transforms into a difficult non-convex, non-smooth and non-linear optimization problem by considering above limitations and characteristics [7]. Therefore, it is crucial to employ an efficient and reliable optimization algorithm to solve the proposed MOMAED problem. Many optimization methods consist of mathematical and evolutionary algorithms have been proposed to solve the MAED problem over the years [8,9]. Regarding mathematical optimizations methods, linear and quadratic programming methods were applied to handle the ED problem [10]. Linear programming was developed in Ref. [11] to handle the transmission-constrained production cost analysis. A decomposition approach using expert systems for non-linear multi-area generation scheduling was presented in Ref. [12]. The Newton-Raphson method was applied to solve the MAED problem [13]. However, this algorithm cannot handle POZ, VPE and multiple fuel type constraints. Even though these techniques can provide a robust optimal solution, but they suffer from non-continuity and non-derivability of the objective function. Therefore, these methods are not suitable candidates for solving the ED problem when POZ, VPE and multiple fuel type are taken into consideration. To cope with these difficulties many meta-heuristic approaches have been employed to solve optimizations problems with complicated objectives and constraints [14,15]. Results obtained by evolutionary algorithms for complex optimization problems have been satisfactory which make these algorithms to be suitable candidates for solving the MAED.

Numerous evolutionary algorithms such as Particle Swarm Optimization (PSO) [16], Differential Evolution (DE) [17] and Real-Coded Genetic Algorithm (RCGA) [18] were employed to solve the MAED problem. Multi-Objective PSO (MOPSO) algorithm was introduced in Ref. [19] for multi-objective MAED problem. Different types of DE algorithms equipped with time-varying mutation were proposed to solve reserve constrained MAED problem [17]. An Artificial Bee Colony (ABC) optimization algorithm was introduced for solving MAED in Ref. [20] where the obtained results were compared with DE, Evolutionary Programming (EP) and RCGA. A Penalty Function-Hybrid Direct Search Method (PF-HDSM) was proposed in Ref. [21] to investigate multi-area economic generation and reserve dispatch. A dynamically controlled PSO was proposed for solving reserve sharing MAED problem [22]. Four different optimization algorithms including Teaching Learning Based Optimization (TLBO), Evolutionary Programming (EP), RCGA and DE methods were implemented in Ref. [23] to solve the MAED problem. A hybrid DE-PSO algorithm was introduced in Ref. [24] to solve various types of MAED problem including Reserve Constrained MAED (RCMAED) and Reserve Constrained Multi-Area Environmental/Economic Dispatch (RCMAEED). Two main versions of MAED problem, including static and dynamic MAEDs were solved in Ref. [25] by a Nature Inspired (NI) heuristic optimization approach. A New Symbiotic Organisms Search (NSOS) algorithm was developed in Ref. [26] to solve large-scale Multi-Area Economic/Emission Dispatch (MAEED) problem. A new optimization algorithm based on Uniform Distribution PSO (UDPSO) algorithm was presented in Ref. [27] to investigate the Multi-area Multi-fuel Economic-Emission Dispatch (MMEED) problem considering practical constraints at the presence of Generalized Unified Power Flow Controller (GUPFC) device. Privileges of evolutionary algorithms have introduced them as reliable choices for solving complex optimization problems. In other words application of evolutionary algorithms on complex optimization problems such as multi-area economic dispatch has become an ongoing avenue of research.

Besides the advantages of evolutionary algorithms, they have some drawbacks such as trapping in local optima and converge to the global or near-global solution in long time. There are several strategies that can boost the efficiency of evolutionary algorithms such as hybridization of these algorithms to profit their individual advantages and cope with the possible drawbacks that these algorithms might have when they are employed individually. Note that hybridization strategy can accelerate convergence speed and maintain candidate solutions' diversity. In this connection, this paper presents a new robust, powerful and fast hybrid evolutionary algorithm based on PSO and Shuffle Frog Leaping Algorithm (SFLA) for solving the MOMAED problem.

Two different objective functions including generation cost, and emission are investigated. It is usual to obtain a set of optimal solutions instead of one since these objectives are in conflict. Therefore, a multi-objective mechanism capable of finding Pareto-fronts is implemented to find all Pareto-optimal solutions. Moreover a repository is employed for saving all non-dominated solutions at each iteration. In addition, a fuzzy decision making strategy is utilized to sort all Pareto-optimal solutions based on their importance. Yet another, three criterions including Generational Distance (GD), Spacing Parameter (SP) and Diversity Metric (DM) are implemented to analyze obtained Pareto-optimal solutions. Note that, the proposed approach is expandable to handle more objective functions.

The contribution of the presented paper is threefold. First of all this paper present a new evolutionary algorithm to solve complex optimization problems. Second of all a new approach for handling power balance constraint, the most complicated constraint in the MAED problem, is proposed in this paper which distinguishes this work from those in literature. Finally, different less-studied practical constraints are investigated to generalize the presented framework.

The proposed algorithm is applied on two test systems including three-area 10-units and four-area 40-units systems in order to