



A general model for energy hub economic dispatch



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HIGHLIGHTS

- Modeling the economic dispatch of energy hubs.
- Proposing a new optimization algorithm namely SAL-TVAC-GSA.
- Considering electricity, gas, heat, cool, and compressed air as energy carriers.
- Including the valve-point loading effect and prohibited zones of electrical power-only units.

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ABSTRACT

This paper proposes a new optimization algorithm, namely Self-Adoptive Learning with Time Varying Acceleration Coefficient-Gravitational Search Algorithm (SAL-TVAC-GSA), to solve highly nonlinear, non-convex, non-smooth, non-differential, and high-dimension single- and multi-objective Energy Hub Economic Dispatch (EHED) problems. The presented algorithm is based on GSA considering three fundamental modifications to improve the quality solution and performance of original GSA. Moreover, a new optimization framework for economic dispatch is adapted to a system of energy hubs considering different hub structures, various energy carriers (electricity, gas, heat, cool, and compressed air), valve-point loading effect and prohibited zones of electric-only units, as well as the different equality and inequality constraints. To show the effectiveness of the suggested method, a high-complex energy hub system consisting of 39 hubs with 29 structures and 76 energy (electricity, gas, and heat) production units is proposed. Two individual objectives including energy cost and hub losses are minimized separately as two single-objective EHED problems. These objectives are simultaneously minimized in the multi-objective optimization. Results obtained by SAL-TVAC-GSA in terms of quality solution and computational performance are compared with Enhanced GSA (EGSA), GSA, Particle Swarm Optimization (PSO), and Genetic Algorithm (GA) to demonstrate the ability of the proposed algorithm in finding an operating point with lower objective function.

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1. Introduction

Future vision of energy networks including several energy carriers in the form of multi-carrier systems [1] (also, called multiple energy carrier networks [2] or hybrid systems [3]), allows more flexibility in the integrated network operation and optimization [4,5]. In fact, various infrastructures can affect each other in terms of energy flow, storage, etc. In the meantime, energy hubs play an essential role in the connection points between different infrastructures allowing energy flow through various networks. Combination of several converters in hubs provides necessary motivations to integrate multiple energy carriers [3]. Some con-

verters such as CHP devices [6–9] and tri-generations [10–13] in the hubs are two attractive cases which can establish more effective energy conversion between different carriers [1,3,4,6]. In this regards, other elements (such as heater exchangers) may operate with a single carrier. In this view point, various carriers can be consumed by different hub structures to provide different forms of energy at the output port.

Proposing the different optimization problems for electrical systems will be lead to introduce two problems, namely Multi-Carrier System Optimal Power Flow (MCSOPF) and Energy Hub Optimal Dispatch (EHOD), for hybrid systems. The first one, optimizes the energy flow through various networks based on a desirability e.g. energy cost, emission cost, energy loss, and etc. [1,2,4]. So, the system condition in terms of all control and state variables, energy flows and the other quantities can be determined. Due to different

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structures associated with various energy infrastructures, the MCSOPF is a non-convex, non-smooth, nonlinear, and high-dimension optimization problem. Therefore, finding the global optimum could not to be guaranteed [3]. The EHOD optimizes a single hub neglecting the energy transmission losses [2]. The basic questions which should be answered by EHOD are how much of the available carriers at the input port of a hub should be consumed and how should they be converted in order to satisfy the demands at the hub outputs. In other words, this optimization process determines the optimal energy input subject to energy flow through the hub and load supplying.

The work presented in [2], introduces the hub concept and its modeling and optimizes a hybrid system including electrical and gas networks. The MCSOPF problem in [2] provides a general formulation which can be employed for various electrical and pipeline systems. In this context, [1] applied a decomposition method to MCSOPF. This approach uses virtual units and dummy variables to construct the problem. This makes a complex OPF problem involved with additional variables and constraints. An energy flow optimization of hybrid systems based on a modified version of teaching-learning algorithm has been reported in [4]. This reference optimizes multicarrier system including electrical, gas, and heat infrastructures. Authors of [3], analyzed the impact of heating systems on hybrid networks in terms of OPF. Another method based on employing an appropriate set of dependent variables has been proposed in [14]. In fact, in order to convert irregular equations into a regular set, it eliminates the addition of any new variable. A similar approach has been reported in [15]. In [16], a Gravitational Search Algorithm with Time Varying Acceleration Coefficient (TVAC-GSA) has been applied to MCSOPF problem. This method is based on the gravitational law and law of motion. In [17], multi-agent systems are used to optimize and control multiple energy carriers. The work reported in [18], studies the interactions in district electricity and heating systems. A combined analysis of these grids can be found in [19]. Optimal operation of integrated electrical and heating systems to accommodate the intermittent renewable sources has been proposed in [20]. Ref. [21] presented a model for integrated analysis of electricity, heat and gas networks. A similar work to form an integrated OPF for multiple energy networks has been developed in [22].

Ref. [2] suggested EHOD problem of an energy hub and described the related optimization process. Effect of energy hubs on the hybrid systems has been discussed in [23]. A generic framework for modeling of energy systems based on the hub concept has been suggested in [24]. In [25], a medium-term energy hub management based on electricity price as well as wind uncertainty has been documented. Ref. [26] modeled an Economic Dispatch (ED) of multiple energy carriers considering wind energy (i.e. [27]) through a multi-agent genetic algorithm. This reference considered only one structure for all hubs with three forms of energy and without investigating a set of hubs which supply load. Also, in [26], the energy cost has been minimized only without considering the optimization of hub losses or a multi-objective problem (such as simultaneously minimizing the energy cost and losses of a set of hubs). In addition, some operational challenges such as valve-point loading effect and prohibited zones have not been taken into account.

1.1. Motivation, contribution, and novelty

ED in the power systems is a well-known problem and it is one of the most heavily used tools in the power system studies. It responses to schedule the committed outputs of all available generation units to meet the load demand at the minimum operating cost as well as satisfying different equality and inequality constraints [28]. The CHPED [29] is an extension version of the

economic dispatch and can be considered as a special case of MCS problems in which two forms of energy, i.e. electricity and heat, are optimized simultaneously [6]. In the viewpoint of hub, the CHPED can be modeled with different hubs constructed by three elements including transformer (with 100% efficiency), CHP unit, and heater exchanger (with 100% efficiency). Fig. 1 shows this concept.

In this paper, motivation of CHPED modeling, based on the mentioned viewpoint, is extended to various hub structures with different converters and elements. So, an optimization framework is presented to formulate this new problem. It is mainly due to the fact that at this stage of the advancement of MCS, there is still needs to be put under examination in both modeling and operating concerns. Economic energy dispatch and conversion in the hubs are two main issues in the MCSs. In this condition, the classical ED methods should be modified to meet the system requirements like optimal conversion between different carriers.

The new proposed modeling, which is called Energy Hub Economic Dispatch (EHED), states a general economic representation covering a wide range of energies and hubs including different converters. This problem schedules the committed input carriers available at the hub inputs to meet different types of demands at minimum operating cost while satisfying various operational constraints. In other words, EHED allows finding an optimal operating point in terms of satisfying different equality and inequality constraints, supplying the various forms of load demands efficiently and economically, and searching the global optimum (or a

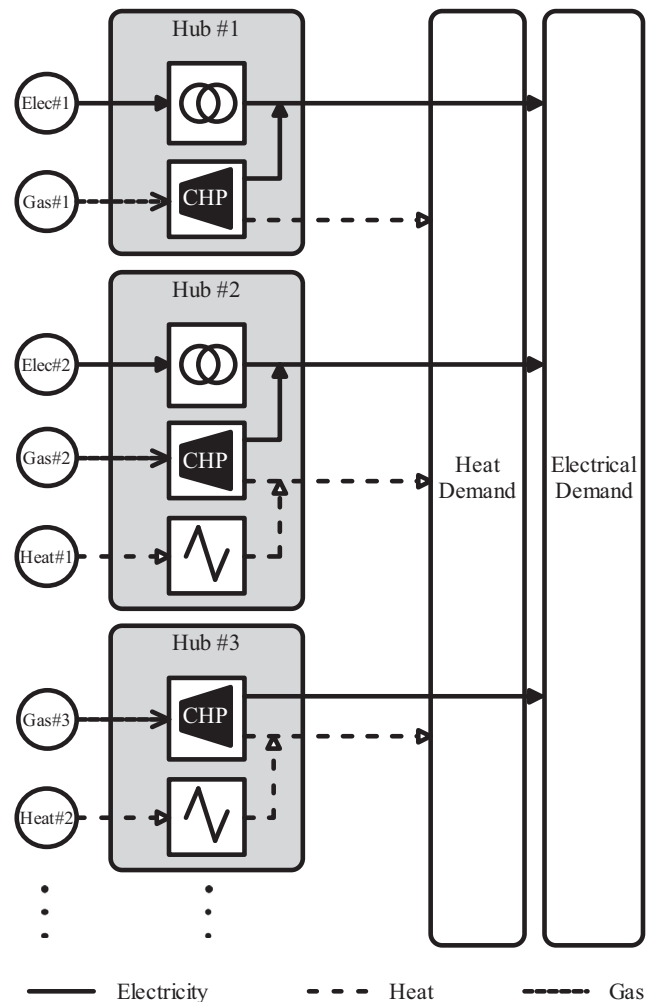


Fig. 1. A general representation of CHPED based on the hub concept.

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