Energy 114 (2016) 253–265

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Optimal operation of multicarrier energy systems using Time Varying Acceleration Coefficient Gravitational Search Algorithm

Soheil Derafshi Beigvand [a], Hamdi Abdi [a, *], Massimo La Scala [b]

[a] Department of Electrical Engineering, Razi University, Kermanshah 67149-67346, Iran
[b] Electrical and Electronic Department (DEE), Polytechnic School of Bari (Politecnico di Bari), Bari, Italy

ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form
11 July 2016
Accepted 30 July 2016

Keywords:
Energy hub
Gas pipeline network
Modified gravitational search algorithm
Hybrid system
Multicarrier systems
Multiple energy carriers
Optimal operation
Optimal power flow
Valve point loading effect

ABSTRACT

This paper describes a novel modified optimization algorithm based on a new heuristic method, namely Time Varying Acceleration Coefficient Gravitational Search Algorithm (TVAC-GSA), to solve both single- and multi-objective Optimal Power Flow (OPF) problems in hybrid systems especially focusing on electricity-gas network. The suggested method is based on the Newtonian laws of gravitation and motion. Sum of the complexity of both electrical and gas-based networks in terms of the valve-point loading effect of generator units, energy hub structure, energy flow equations, and different related equality and inequality constraints make the optimization problem highly nonlinear, non-convex, non-smooth, non-differential, and high-dimensional. The effectiveness of the proposed algorithm to solve such a complex problem is verified on a new introduced hybrid system based on a modified version of IEEE 14-bus network. Comparison of results obtained by the presented method with those obtained by GSA, Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Differential Evolution (DE) shows the better accuracy and fast convergence of the new method in finding an operating point with lower objective function value.

1. Introduction

Nowadays, employing different forms of energy in power systems have resulted in essential changes in the operation. Utilizing scope of small size Combined Heat and Power (CHP) units, energy conversion based on the new equipment, Distributed Generation (DG), use of multiple energy carriers in industrial parks, and large tertiary facilities has affected this system significantly. So far, various factors such as more efficiency and less cost have been separately mentioned in the operation of different energy infrastructures. Recently, an integrated view of energy networks has been suggested in which different energy carriers such as electricity, and natural gas are optimized simultaneously. This strategy has more flexibility in the optimal operation of multicarrier systems employing different forms of energies. In this context, the necessary motivations to integrate multiple energy carriers are caused by several converters combinations in a specific structure, namely energy hub [1]. Gas-fired [2], other dispersed generations [3,4], CHP units [5,6], and tri-generations in the hubs provide a more effective power conversion between various carriers [1,7,8]. As a result, different types of energy can be consumed and converted through an energy hub to supply various forms of demands.

Since traditional methods optimize only one form of energy, thus, they can be extended to a novel operation concept in which different forms of energy are optimized simultaneously. Without claiming to be exhaustive, three examples of traditional approaches can be found in Refs. [9–11]. In Refs. [11], the OPF problem of electrical networks which is the basic literature in the operational field was proposed. Optimization of a gas-based pipeline system using dynamic programming was used in Ref. [9]. District heating network as a single carrier system was optimized in Ref. [10]. Later on, an integration view of several carriers was considered. For example, in Refs. [12], a general framework was developed to describe municipal and regional energy networks in terms of dataflow systems. A dynamic and stochastic optimization of primary energy demand, emissions of pollutants, and monetary cost was provided in Ref. [12]. In Refs. [13], natural gas and electricity Optimal Power Flow (OPF) were presented in which the energy conversion between electrical and gas systems at the generators was considered. Optimization of energy hubs in the form of a new

* Corresponding author.
E-mail addresses: soheil3240@yahoo.com (S. Derafshi Beigvand), hamdiabdi@razi.ac.ir (H. Abdi), massimo.lascala@poliba.it (M. La Scala).

http://dx.doi.org/10.1016/j.energy.2016.07.155
0360-5442/

concept, namely optimal power dispatch, was addressed in Ref. [14]. In this reference, a general optimization technique for power conversion and dispatch in the power systems considering several energy carriers such as natural gas, electricity, and district heating was introduced. The OPF problem of multicarrier networks focusing on energy hubs was suggested in Ref. [1]. A decomposed solution applied to this problem could be found in Refs. [7], in which the main problem was decomposed into separate single energy carrier OPF problems. Also, optimization of energy flow in multiple energy carriers was implemented in Ref. [8] through a modified teaching-learning based optimization.

Recently, a novel heuristic search algorithm based on the Newtonian laws has been proposed in Refs. [15], namely Gravitational Search Algorithm (GSA). This new algorithm has been successfully applied to various nonlinear functions and results demonstrated its high performance as well as its enough flexibility to enhance exploitation and exploration abilities. Because of its characteristics, a modified version of it (called Time Varying Acceleration Coefficient − GSA or TVAC-GSA) seems to be a good candidate to solve difficulties linked to the real world optimal energy flow problems and as long as authors know that it has not been proposed, formulated, analyzed, and tested on this type of problems before.

In this paper, a new algorithm based on the introduced TVAC-GSA to solve the Multiple Energy Carriers Optimal Power Flow (MECOPF) problem is proposed which focuses on electric-gas network as a source-transmission system and electricity-heat loads as the main demands. In fact, a heuristic approach is proposed to solve convergence difficulties due to the structure of the problem which cannot be overcome with more classical optimization algorithms (gradients-based, interior point, quasi-Newton methods, and etc.). Furthermore, performances of different algorithms are compared mainly on the basis of economical benefits which can be reached in searching the global optimum (or the less expensive solution) and the related operating point costs.

The main feature of the introduced approach is related to its ability in solving and finding the better solution of non-convex, non-smooth, non-differential, high-dimension, and highly nonlinear OPF problems in multicarrier systems. In fact, the main complexities are associated to multiple energy carriers and their networks, several dispatched energy hubs equipped with CHP units, and valve point loading effect of electrical power-only units. These provide necessary motivations to attain more economical benefits with regard to the other tested algorithms by searching a better optimum solution with good convergence characteristics and a computational time. It should be noted that the contribution in this area derives from the capability of the proposed algorithm in finding a good quality solution without convergence problems and mostly yielding a better optimum which results in economical benefits which is our main performance indicator.

It is important to note that, we mainly focus on electrical and gas networks to show how the optimal operation problem can be derived. Without losing generality, for other carriers, it can be treated similar to the presented approach in this paper. Nevertheless, in the formulation of some components, a general representation is used to drive a specific form. The formulation of this kind of problem is based on the essential components of a hybrid network presented in Ref. [1]. As the final note, use of term "multiple energy carriers" and "multicarrier" in the papers, refer as term "hybrid". Also, term "energy flow" is employed to refer to terms "power flow" and "gas flow".

The rest of the paper is organized as follows. Section 2 describes the basic concepts in terms of multicarrier systems, energy hubs as well as valve-point loading effect. Also, general assumptions considered in this work are listed in this section. Energy flow equations in both electrical and gas-based pipeline networks, energy hub modeling, and MECOPF structure are presented in Section 3. In Section 4, main structure of TVAC-GSA is introduced and different steps of the proposed TVAC-GSA-based MECOPF are described in Section 5. The obtained results are illustrated and compared with various techniques in Section 6. Finally, the conclusions are drawn in Section 7.

2. Basic concepts and assumptions

2.1. Multiple energy carriers

In order to meet demands more efficiently, multicarrier networks are optimized simultaneously. In general, they include several energy infrastructures such as electrical and gas networks. The related systems transmit energy from sources to demand centers, as shown in Fig. 1.

Against single carrier, multiple energy carriers allow more flexibility in the system operation, which is mainly due to increasing the utilization of DGs like CHP units and tri-generations. These devices allow converting a type of energy (gas) into several forms (electricity-heat-cool).

2.2. Energy hub

In general, an energy hub establishes an interface between delivered energy (by transmission networks and/or energy sources) and loads. In other words, each hub acts as a unit which utilizes different forms of energy (such as electricity, natural gas, etc.) at its input ports and provides various energy services (such as electricity, heat, cool, etc.) at the output ports. Also, it enables the integration of an arbitrary number of energy carriers and products [1]. This concept is illustrated in Fig. 2(a). A special hub including transformer, CHP, and a gas furnace as the convertor elements which consumes electricity-natural gas and supplies the electrical-heat demands is illustrated in Fig. 2(b). The basic hub elements can be found in Ref. [1].

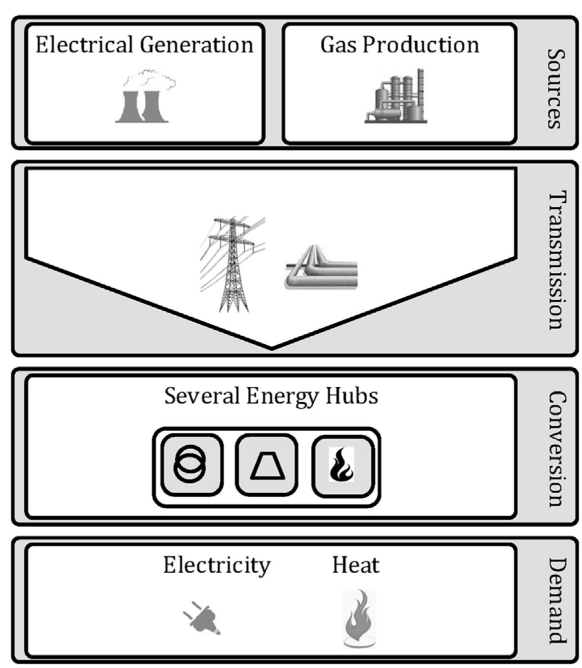

Fig. 1. A schematic layout of a multicarrier energy system.