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Multi-objective operation management of a multi-carrier energy system

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ABSTRACT

In this paper, a multi-objective optimization approach for multi-carrier energy networks is discussed. A multi-carrier energy network is a system consists of various types of energy carrier such as electricity, natural gas, and heat. Minimizing the total cost of operation of such a system is a typical objective for optimization while another important objective is to minimize the total emission generated by the whole network. It is shown in the paper that the cost and emission functions are two opposite objectives that decreasing one of them would increase the other one and vice versa. Therefore, a multi-objective optimization should be utilized to obtain the global optima of the problem based on the priority of each objective. According to the large size of the problem in actual networks, this could be a non-linear, non-convex, non-smooth, and high-dimension optimization problem that mathematical techniques could be trapped in local minima. Hence, it is better to use evolutionary techniques instead. To do so, a fuzzy decision making method is proposed in this paper which is merged with the well-known modified teaching-learning based optimization algorithm. This approach is implemented and applied to a typical multi-carrier energy network to verify the proposed methodology.

1. Introduction

Nowadays, electricity is one of the most common forms of energy in the world. Almost all industrialized parts of countries require electricity. Besides that, there are heating and cooling loads especially in urban areas that should be supplied. These power demands can be covered whether by local generation or by large power stations and transmission systems [1]. The latter is very common in the past but local generations with high efficiency are gradually increased in the system that not only supply part of the loads but also improve reliability of the system and decrease the energy not supplied index.

In an energy network, loads require appropriate forms of power such as electricity and heat. These forms of energy are obtained by other energy carriers such as natural gas, coal, biomass, etc. Therefore, energy carriers are related to each other. For example, a CHP (combined heat and power) unit consumes natural gas and produce electricity and heat. Therefore, natural gas should be delivered to it by, for instance, a gas transmission network. Moreover, the surplus/deficit amount of the generated power by this plant should be transferred to/from the respected networks (the electrical or district heating system in this case). This example shows that sub-networks of an energy delivery system are strongly dependent and their power flows are related to each other. So, for an optimization procedure, these networks should be considered together as a unified system that creates the so-called MCEN (multi-carrier energy network).

An MCEN consists of various energy carriers that can be converted via a well-known concept called energy hubs [2,3]. This integrated viewpoint opens a new window on research of synergies which can be available by combination of electricity, natural gas, heat, and network infrastructures [4]. Energy hubs are an interface between participants and transmission systems that condition, transform and deliver energy in order to cover the consumer needs [5].

The adoption of MCENs as an inventible solution for future vision of energy networks results in the combined modeling and analysis of energy networks [6]. As a matter of fact, a new branch of investigation has been grown recently in which different aspects of previous networks have to be revised based on the MCEN concept.

In Ref. [3], an optimal power flow of MCENs is studied considering electricity and natural gas and the concept of energy hubs. A decomposed technique is presented in Ref. [7] that carries out

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Nomenclature

Subscript

E	electric
G	natural gas
H	heat
s	supply pipeline
r	return pipeline
g	ground

Superscript

hub	energy hub
gen	electric generator
chp	combined heat and power plant
boil	boiler
gs	natural gas source
shc	shunt capacitance
dem	demand
comp	compressor
pump	circulating pump
fuel	fuel
line	transmission line/pipeline
bus	electrical/gas/heat bus
min	minimum limit of a variable
max	maximum limit of a variable

Variables/parameters of the MCEN model

P	electric/gas/heat power (MW)
Q	reactive power (MVar)
S	apparent power (MVA)
ϕ	consumed amount of fuel (m^3/day, ton/day)
f	natural gas flow (m^3/day)
$\dot{m}$	mass flow rate of water (kg/s)
V	voltage magnitude (p.u.)
θ	voltage angle (degree)
π	natural gas pressure (bar)
T	temperature (°C)
G	conductance of transmission lines (s)
B	susceptance of transmission lines or shunt capacitances (s)
TR	tap ratio of tap-transformers
H	compression ratio of compressors
C	constant of natural gas pipelines
D	diameter of gas pipelines (m)
L	total length of gas/heat pipelines (m)
τ	pump head of the district heating network (m)
η	efficiency of units
u, v, w	cost coefficients of fuels
a, b, c, d, e	heat rate coefficients of generators/characteristic coefficients of CHPs and boilers
$\alpha, \beta, \gamma, \xi, \lambda$	emission coefficients of electric generators
χ	emission coefficient of CHPs/boilers
N	total number of units

Variables/parameters of the MTLBO algorithm

X	individual of the optimization problem
F	objective function
T	teacher of the algorithm
M	mean value of the found individuals
W	worst solution among all individuals
rand	a random number between [0,1]
ξ	wavelet function
υ	central frequency of the wavelet function
ς	upper limit of the wavelet function
σ	constant illustrates shape of the wavelet function
φ	a random number between $\pm 2.5h$
μ	fuzzy membership function
ω	weighting factor for objective functions
k	current iteration of the algorithm

Constants

ε	absolute rugosity of natural gas pipelines (0.05 mm)
z	natural gas compressibility factor ($z = 0.8$)
δ	density of natural gas relative to air ($\delta = 0.6106$)
c	specific heat capacity of water ($c_P = 4182$ J/KgK)
ρ	heat transition coefficient ($U = 0.455$ W/mK)
ψ, ζ	constants of compressors ($\psi = 0.167$ for a turbo-compressor, $\psi = 0.157$ for a moto-compressor, and $\zeta = 0.236$ for both types)
g	standard gravity constant ($g = 9.81$ m/s^2)

a central optimal power flow problem by decomposing it into several sub-problems solved in an iterative way, independently but coordinated. The optimization procedure in these papers is established based on the Lagrange function but it is mentioned that this technique cannot be used for larger networks. Some works use approximated techniques for the target of energy flow optimization with supply chains [8]. In Ref. [9], the presented approach tries to use an enhanced modeling framework for the network thorough a reformulation of the energy hubs. It should be mentioned that if the total number of inputs of an energy hub is larger than the total number of its outputs then a set of irregular equations is appeared. In Ref. [6], some dummy variables are proposed to convert these irregular equations into a regular set and a multi-agent genetic algorithm is represented to solve the problem. Although this can successfully deal with the problem but several equality and inequality equations are added to the formulation that increases complexity of the problem. A novel approach based on choosing an appropriate set of state-variables for the problem is proposed in this paper that eliminates the addition of any new variable while the optimization problem is still solvable. Previous researches concentrate on the electrical and natural gas networks. Another transmission network that is very promising for energy saving and carbon emission reduction is the district heating network which is well-developed in a number of Northern European countries [10–12]. In this paper, both hydraulic and thermal part of these networks are also modeled for the MCEN optimization scheme. On the other hand, all previous researches consider only the total cost of operation as the objective function of the problem. However, there are other objectives that might be observed in an optimization process. One of them is the total emission of the system which is an attention-grabbing criterion these days. From an environmental point of view, reducing the CO_2 production as the most important greenhouse gas is claimed by countries signing the Kyoto's Protocol [13]. So, reducing the total emission of an MCEN can be important similar to decreasing its cost of operation. As a matter of fact, a multi-objective approach might be helpful to find out all possible optimized operating points, called Pareto optimal curve and then with an appropriate tool, which is fuzzy logic in this paper, the best compromising solution can be chosen based on the priority of the objectives.