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# Integrated modeling of microgrid for steady-state analysis using modified concept of multi-carrier energy hub

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ABSTRACT

The paper deals with a novel approach to modeling the energy hub for microgrid representation in steady-state analysis. The presented model enables to avoid some limitations identified for the conventional (original) energy hub model. First a mathematical model has been formulated with the use of graph and network theory. Then a proposed model has been verified by steady-state calculations for selected microgrid operation scenario and exemplary energy hub structure. Finally a possible application of the presented model has been identified and future works have been widely discussed.



## Introduction

A power industry in micro scale is currently a significant element of the global debate about renewable energy policy. On the other hand, a development of smart grid technology and energy management concepts is observed. A lot of scientific and research efforts have been made in areas such as: microgeneration and storage technology, controlled energy receivers, auxiliary services for power system operators, etc. [1,2].

A growth of energy efficiency has been seen in a situation in which common managed energy consumers are spatially located in the near area. The energy delivery microsystems called *microgrids* are perfectly fit to the energy efficiency requirements as well as expectations of reducing greenhouse gas emissions [1]. A coordinated operation and control of distributed generation sources together with controllable loads and storage devices is a part and parcel of the microgrid paradigm. From the point of view of a power distribution system operator (DSO), microgrids can be treated as energy prosumers offering not only energy generation to the power system but some auxiliary services as well [3].

Therefore the energy microgrid concept is regarded as an integral element of smart electric power grids. In particular, the developing concepts of microgrid management assume that an energy delivery infrastructure is controlled by a private entity which is able to both produce and consume the energy in different forms, i.e.: electricity, heat and cool [4]. An operator of such microgrid can be an owner of industrial plant or an agricultural farm. Exemplary diagram of a microgrid managed by a private entity is presented in Fig. 1.

In order to achieve a synergy and convergence effect obtained in a simultaneous analysis of different energy carriers, it is necessary to apply a mathematical representation of multi-carrier energy system to microgrid modeling [5]. The model of multi-carrier energy system can be defined as a representation of energy delivery system by multiple energy carriers which associates power load or embedded generation, energy transmission/distribution infrastructure as well as devices suitable for: energy conversion between particular carriers, transformation of energy parameters and energy storage.

The most important element of the model of a multi-carrier energy system is the so-called "energy hub". It has been defined as an interface between energy producers, consumers, and the transportation infrastructure. From the point of view of the system, the energy hub is a unit providing the features such as: in- and output, conversion, and storage of multiple energy carriers [6–8]. Fig. 2 shows a simple example of a multi-carrier energy hub including an electric transformer, a gas microturbine and a gas boiler. It should be emphasized that there is no transmission representation in an energy hub model. Energy hub should be used to see a simplified behavior outside of it and not to analyze power phenomena in details.

As mentioned, the energy hub concept can be a used in a microgrid model. One can consider the energy hub as a whole microgrid or as its part, e.g. a building, settlement, etc. This paper considers the former application of the energy hub, i.e. the one-hub microgrid model. Such an approach is especially useful for a planning

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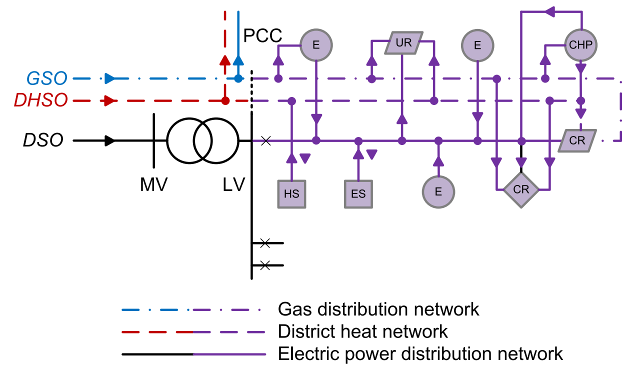


**Fig. 1.** Exemplary structure of energy microgrid managed by individual private entity; abbreviation designation: GSO – gas distribution system operator, DHSO – district heat system operator, DSO – electric power distribution system operator, PCC – multipoint of common microgrid coupling, E – electric power source, EH – combined heat and electric power source, H – heat source, ES – electric power storage, HS – heat storage, CR – controlled energy receiver, UR – uncontrolled energy receiver.

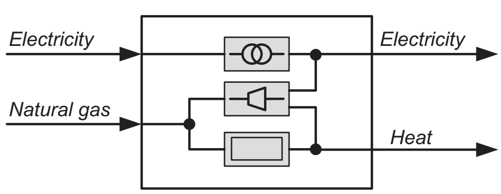


**Fig. 2.** Exemplary structure of simple energy hub.

the generation-storage structure of a microgrid where steady-state analysis is preferred.

## Problem statement

The energy hub concept have been originally developed by Geidl et al. [6–8], focusing on their in- and output power flows while considering the device as a black-box characterized by its energy efficiency. Below a conventional model of energy hub have been presented.

Let a converter and two storage device be considered as indicated in Fig. 3 that converts an input energy carrier $\alpha$ into $\beta$, where $\alpha, \beta \in \mathcal{E}$ and $\mathcal{E}$ is a set of energy carriers, e.g.: electricity, natural gas, heat, cool, hydrogen, diesel, etc. Input and output of the energy converter can be coupled as [8]:

$$\widetilde{L}_\beta = c_{\alpha|\beta}\widetilde{P}_\alpha \quad (1)$$

where $c_{\alpha|\beta}$ is the coupling factor between input and output power flow which corresponds to the converter steady-state energy efficiency $0 \leqslant \eta_{\alpha|\beta} \leqslant 1$.

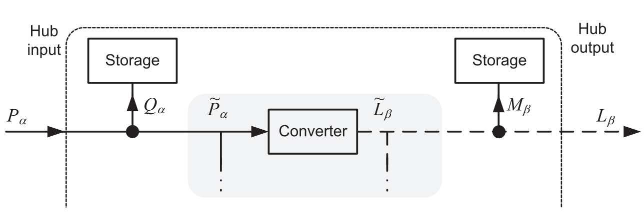


**Fig. 3.** Conventional model of energy hub including the converter and storage devices.

The equations corresponding to input and output side of storage are [8]:

$$\widetilde{P}_\alpha = P_\alpha - Q_\alpha \quad (2)$$

$$\widetilde{L}_\beta = L_\beta + M_\beta \quad (3)$$

Formulas (1)–(3) can be generalized to a model covering couplings with multiple in- and outputs. On can use matrix formulation such as [8]:

$$\mathbf{L} = \mathbf{C}[\mathbf{P} - \mathbf{Q}] - \mathbf{M} \quad (4)$$

where $\mathbf{C}$ is a coupling matrix which elements are coupling factors as mentioned in (1), $\mathbf{P}$ and $\mathbf{L}$ are vectors stating all input and output power variables respectively, $\mathbf{Q}$ and $\mathbf{M}$ are vectors keeping all input and output side storage power flow respectively.

The details about conventional steady-state model of energy hub as well as corresponded formulas derivation can be found in [7,8].

Considering the presented conventional model of energy hub the following limitations have been observed:

- an unidirectional power flow from the inputs to the outputs of the converters is assumed; reverse power flow is possible for some technology which enables bidirectional flows, e.g.: electric transformers, power electronic converters, reversible fuel cells [9,10];
- input and output terminals of energy hub model are associated with energy delivery infrastructure (energy supply) and power load respectively; the following question appears: how to represent renewable energy resources such as wind, sunlight, potential energy of water; to which terminals (input, output) should they be connected?
- input and output are given *explicite*; the following dilemma often exists: to which terminals (input or output) energy prosumers should be assigned?
- it is not possible to connect two output terminals by an energy converter (e.g. absorption chiller); the same problem concerns the input terminals.

A modified concept of the energy hub has been already raised in literature. For instance in [11] an uncertainty conditions in optimization problem has been introduced. The uncertainty concerns the prediction of renewables as well as the reliability of particular energy hub elements. A detailed approach to optimization constraints formulation has been presented in [12]. The constraints include a more realistic representation of converters and storage devices. Also, the matrix $\mathbf{C}$ is reformulated to get an assumed flexibility. In [13] a robust optimization technique has been proposed to solve an energy hub operation problem, while an energy hub model is similar as the conventional one.

This paper focuses on a new modified model of energy hub. The proposed model enables to avoid the aforementioned limitations which have been identified for conventional energy hub model. First a new mathematical model has been formulated assuming that:

- there is no distinguishing between input and output terminals;
- bidirectional power flow is available for selected converters.

In order to achieve the assumed model goals the graph and network theory has been used. The proposed model has been also verified analyzing steady-states for exemplary structure of energy hub and selected scenario of predicted values of power consumption and generation.