Journal of Energy Storage 5 (2016) 187–202

Contents lists available at ScienceDirect

Journal of Energy Storage

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

Thermo-economic analysis of the energy storage role in a real polygenerative district

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ARTICLE INFO

Article history:
Received 6 November 2015
Received in revised form 30 December 2015
Accepted 9 January 2016
Available online 3 February 2016

Keywords:
Microgrid
Cogeneration
Electric storage
Thermal storage
Thermo-economic analysis

ABSTRACT

This paper presents a thermo-economic analysis based on data from a real Smart polygeneration microgrid (SPM), designed to satisfy energy demands of the university campus of Savona (Italy). The plant is made up of different cogenerative generators (micro gas turbines and an internal combustion engine), renewable generators and two auxiliary boilers (one of them is off during the most of the time): the generators are "distributed" around the campus and coupled to electrical and thermal storages. Since several cogenerative units are included in the grid, the integration of the different storage systems is relevant in order to determine the best management strategy, following both thermal and electrical requests and taking into proper account the strong difference between the two energy demand profiles.

The thermo-economic analysis is performed exploiting the software W-ECoMP, developed by the authors' research group, in order to find the best operational strategy, considering the importance of an appropriate storage system to manage the polygenerative energy district; attention is paid to the integration and combination of three different kinds of storage (hot and cold water tanks and electrical battery). Different scenarios are presented, combining the storages and showing their impact in terms of money savings and reduction of electrical energy purchasing from the National grid. Both the grid connected mode and island mode of operation of the SPM are considered.

The analysis is performed considering the time dependent nature of the energy demands throughout the whole year and implementing the experimental off-design curves of the real devices installed in the grid.

1. Introduction

Polygeneration and Distributed generation (DG) are two energy concepts that are becoming increasingly popular for the many advantages they offer in terms of energy savings and reduction of emissions; consequently research has been ongoing in order to improve the best solution and easily interconnect this new concept in the present energy scenario. Nowadays in Europe nearly half of the energy consumption is needed in the heating sector and, at the same time, the energy demand for cooling and air-conditioning is rising rapidly [1,2]. Therefore, promotion and use of renewable energy heating and cooling systems and equipment have become necessary to fulfill the European targets in the renewable energy sector, as well as to significantly contribute to the reduction of energy consumption and energy import dependence [3]. As a result, due to a cooperative effort among researchers and government agencies [4], several innovative efficient systems have been investigated about polygeneration and DG. These two energy concepts are intrinsically interconnected, as different energy technologies can be integrated in polygenerative districts including CHP (Combined Heat and Power), energy storage (both electrical and thermal energy storage), Renewable Energy Sources (RES) generators, multi-fuel heating, electric and non-electric chilling. In particular, energy storage can significantly enhance the performance of distributed generation as shown in many recent investigations about the impact of Thermal Energy Storage (TES) in polygenerative districts [5,6]. Furthermore, DG aims to concentrate energy production close to the users, reducing or avoiding thermal and electric losses through the grid and reducing the size of generators, both traditional and RES, distributing them in different locations [7]. Nevertheless, according to the unpredictability of

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Abbreviations: CHP, combined heat and power; CSP, concentrating solar power; DG, distributed generation; LHV, lower heating value; mGT, micro gas turbine; RES, renewable energy sources; SOC, state of charge; SPM, smart polygenerative microgrid; TES, thermal energy storage; W-ECoMP, web-based economic cogeneration modular program.

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http://dx.doi.org/10.1016/j.est.2016.01.001

Nomenclature

Variables

C	Cost [€]
c	Specific cost [€/kWh]
E	Electricity flow [kW]
F	Fuel consumption [kg]
Q	Heat flow [kW]

Subscripts and superscripts

acq	Acquired
c	Charging
cap	Capital
cons	Consumed
el	Electrical
i	i-th step
prod	Produced
req	Required
s	Discharging
var	Variable
virt	Virtual

many RES and the different peak moments for thermal and electrical energy demands in the district, storage and efficient control strategies are needed.

Thermo-economic analysis is a well known method to approach energy systems, in order to develop efficient and profitable real time controllers and to identify the best size for the different installed devices. Energy storage systems can help in successfully meeting the district energy demand, such as building heating and cooling applications, and they are able to solve the problems of not dispatchable renewable energy sources in the electrical market. Moreover energy storage provides more efficient and environmentally-benign energy utilization as they are employed to supply energy in an efficient way where there is a mismatch between energy utilization and production [8]. Some general benefits of the energy storage may become reduced energy cost and consumption, conservations of fossil fuels, compact equipment size, reduced emissions and higher efficiency [9] [10].

There are limited studies on thermo-economic analysis of energy storage systems in the open literature. Most of them are focused on the use of thermal storage in district heating systems [11] or coupled to solar thermal collector systems [12] to store the excess of production, often analyzing [13] the charging and discharging processes of the sensible heat TES systems to find the performance of the systems with minimum cost of maintaining and operating.

Otherwise thermo-economic analysis is often applied to optimize energy systems, in cogenerative and polygenerative configurations [14,15], as it is strictly connected to exergetic and energetic balance analysis.

In this paper, according to the authors' experience on thermo-economics of energy systems [8,10], an innovative approach to evaluate the thermo-economic value of energy storage in polygenerative district is presented. This approach is based on the primary energy cost of the whole system through an evaluation of real and fictitious variable costs related to energy storage operations.

The purpose of this paper is to optimize the management of a real polygenerative energy district installed at the University of Genoa campus located in Savona [16] managing local generators to satisfy thermal (heating and cooling) and electrical load demands of the district and managing in the optimal ways the energy storage installed in the demonstrator. A one-year analysis is carried out with one hour time intervals, taking into proper account the time-dependent nature of energy demands, RES generation and investigating the best operational strategy for the devices, with particular focus on storage technologies. Different scenarios are presented combining three different kinds of storage: hot water tank, cold water tank and electrical battery. The features of such storages were derived from the actual equipment installed.

The optimization process is performed employing the original software W-ECoMP (Web-based Economic Cogeneration Modular Program) [16,17], which aims to investigate the best management strategy of the devices installed in polygenerative energy districts in order to satisfy the load energy demands and make eventual new equipment installations profitable.

2. Polygenerative district layout

The plant investigated in the present paper is the Smart Polygenerative Microgrid (SPM) shown in Fig. 1: it represents one of the three demonstrator sites of the European Project FP7 RESILIENT [18].

The SPM installed in Savona is quite complex, including several commercial CHP units, traditional prime movers and not predictable renewable generators, The CHP units features, which are all fuelled by natural gas, are reported in Table 1. The functioning percentage values of each generator are the optimization variables for the research presented in the following sections.

The following renewable generators are also present in the test case site:

- A photovoltaic roof of 400 m^2, corresponding to a peak power of about 77 kW$_e$;
- Three CSP dish Stirling units, each rated 1 kW$_e$, 3 kW$_{th}$ [23];

The storage equipment already installed in the SPM are presented here below:

- Two storage tanks for hot water, for a total volume of 10,000 l;
- A storage tank for cold water, volume of 3000 l;
- A FIAMM SoNick electrical energy storage, capacity of 470 Ah and nominal voltage of 300 V [25].

The SPM is connected to the National electrical grid in a single point and it is able to both sell and purchase electrical energy. It is worth noting that the CSP dish Stirling units (Fig. 1) contribution to the grid is not considered in the present analysis, since their thermal and electrical production is almost negligible.

3. A thermo-economic approach for the investigation of energy storage

Thermo-economics aims to find a correlation between the thermodynamics, particularly energy and exergy flows, and the economics of an energy system. The peculiarity of this thermo-economic analysis consists in the use of the concepts of specific consumption of components or processes and the energy costs of the flows; these two items of cost constitute the so-called internal economy of the energy conversion system.

Thermo-economic analysis can be insightful in polygenerative districts, where the energy manager has to decide whether i.e., follow the thermal or electrical demands, and optimize the electricity exchanged with the grid.

The objective of thermo-economics is to indicate where and how energy and money savings are possible and to quantify the results obtained in terms of fuel or money saved.