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Optimal sizing of a multi-source energy plant for power heat and cooling generation

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ABSTRACT

Multi-source systems for the fulfilment of electric, thermal and cooling demand of a building can be based on different technologies (e.g. solar photovoltaic, solar heating, cogeneration, heat pump, absorption chiller) which use renewable, partially renewable and fossil energy sources. Therefore, one of the main issues of these kinds of multi-source systems is to find the appropriate size of each technology. Moreover, building energy demands depend on the climate in which the building is located and on the characteristics of the building envelope, which also influence the optimal sizing.

This paper presents an analysis of the effect of different climatic scenarios on the multi-source energy plant sizing. For this purpose a model has been developed and has been implemented in the Matlab® environment. The model takes into consideration the load profiles for electricity, heating and cooling for a whole year. The performance of the energy systems are modelled through a systemic approach. The optimal sizing of the different technologies composing the multi-source energy plant is investigated by using a genetic algorithm, with the goal of minimizing the primary energy consumption only, since the cost of technologies and, in particular, the actual tariff and incentive scenarios depend on the specific country. Moreover economic considerations may lead to inadequate solutions in terms of primary energy consumption.

As a case study, the Sino-Italian Green Energy Laboratory of the Shanghai Jiao Tong University has been hypothetically located in five cities in different climatic zones. The load profiles are calculated by means of a TRNSYS® model. Results show that the optimal load allocation and component sizing are strictly related to climatic data (e.g. external air temperature and solar radiation).

1. Introduction

One of the strategies for the reduction of primary energy consumption in buildings is the improvement of the energy efficiency of the energy plant. This result may be achieved not only through the use of more efficient energy technology, but also through an accurate design of the components of the energy plant [1]. The availability of systems that use renewable energy and small cogeneration systems has led to a progressive integration of different energy sources. A possible further diffusion of small cogeneration systems [2,3] should not ignore the other competing technologies for the generation of thermal and electric energy.

In recent years, growing attention has been placed on multi-source energy plants to fulfil building energy demands. Many examples can be found in literature.

Corrado and Fabrizio [4] studied the combination of wood boiler, condensing boiler, heat pump and solar energy (both thermal and photovoltaic). Sontag and Lange [5] combined cogeneration with solar energy and with wind energy. Trillat et al. [6] combined CHP with absorption chiller and desiccant cooling and Lee et al. [7] studied an integrated renewable system composed of solar water heating, solar photovoltaic, ground source heat pump, electric chiller and gas fired boiler.

In such a scenario of available energy sources (both fossil and renewable) and technologies (e.g. CHP, wind power, solar photovoltaic, solar thermal collector, solar cooling and heat pumps), it is necessary to define methods and guidelines that help to configure and manage a complex system in order to optimize the exploitation of fossil and renewable sources in terms of environmental impact

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Nomenclature

AB	auxiliary boiler
ABS	absorption chiller
AC	auxiliary chiller
ASHP	air source heat pump
CCHP	combined cooling, heat and power
CHP	combined heat and power
COP	coefficient of performance
E	energy
EER	energy efficiency ratio
GA	genetic algorithm
GSHP	ground source heat pump
HP	heat pump
I	radiation
ICE	internal combustion engine
P	power
PE	primary energy
PES	primary energy saving
PV	solar photovoltaic
SH	solar thermal
T	temperature
η	efficiency
μ	penalty coefficient
a0	optical efficiency
a1, a2	correction factor

Subscript

av	available
cold, c	cold
DEM	demand
el	electricity
ex	exchanged
f	fuel
grid	electric grid
l&a	electricity for lighting and appliances
max	maximum
min	minimum
nom	nominal
PRO	production
SP	separate production
th	thermal
usd	used

and economic performance [8,9]. Morini et al. [10] presented a methodology for the optimal allocation of the demands for building cooling, heating and power among CHP and renewable energy systems, in order to minimize the primary energy consumption and draw some general guidelines. This analysis does not consider demand profiles, which depend on several factors such as user type (household, commercial, industry, etc.), user equipment, climate (external air temperature, solar radiation) and human factors (consumption patterns, habits, etc.), but only annual overall demands are taken into consideration. Thus, the proper sizing of the component of the integrated energy system was not performed.

The choice and the sizing of a multi-energy system must be based on the efficient match between building energy demand and supply. Different environmental conditions determine different energy demand for space heating and space cooling. The integration with energy systems that use renewable energy raises additional problems during the analysis since their sizing and operation is greatly dependent on the specific location. Due to the number of variables involved and because of their multiple interrelations, a complex problem arises.

The choice between different plant solutions will be made on the basis of an energy-based criterion. In this study the minimization of primary energy consumption is the only criterion applied, since the cost of technologies and, in particular, the actual tariff and incentive scenarios depend on the specific country and economic considerations may not lead to optimal solutions in terms of primary energy consumption.

A genetic algorithm (GA), which can resolve nonlinear optimization problems, is adopted for the optimization analysis. GA is a metaheuristic technique that can resolve computational problems. The need to provide a solution in a reasonable time discourages the use of exact type approaches (enumerative method), resorting instead to techniques capable of providing good solutions in reasonable times. In general, the solution found is not necessarily a global minima. To improve the solution, appropriate techniques are used to avoid terminating in a local minima (i.e. genetic operators).

Genetic algorithms, introduced by Holland in 1975 [11], have been applied to different scientific, engineering and economic problems. Regarding energy system applications, Obara and Kudi [12] applied a GA method to control problems of energy systems consisting of fuel cells, thermal storage and heat pumps. Ooka and Komamura [13] used GA for solving the optimization of an energy system with electric refrigerator and heat pumps. Wang et al. [14] applied GA to investigate optimal size and operation of a CCHP system. Barbieri et al. [15] used GA to find the optimal operation strategy of CHP combined with a thermal storage.

In this paper, a procedure for the sizing of the integrated energy system components in order to meet actual demand profile is implemented. Then, referring to a building case study, different locations in different countries are considered in order to assess the size of a multi-source energy plant that minimizes the primary energy consumption, by using a genetic algorithm.

2. Model development

A methodology has been developed in order to model and optimize the design of a multi-source energy plant. The analysis has been carried out on an hourly basis. The value of energy demands and their hourly distribution are required as input data. The simulation takes into account the variability of the performance of the energy systems according to both external air temperature and load.

The multi-source energy plant is composed of different kinds of systems which use different energy sources. Renewable energy systems, partially renewable energy systems, systems powered by natural gas and systems powered by electricity are taken into account. As reported in Fig. 1, solar photovoltaic (PV), solar heating (SH), cogenerators (CHP), absorption chillers (ABS), reversible ground source heat pumps (GSHP) and reversible air source heat pumps (ASHP) are modelled. Condensing boilers (AB) and electric chillers (AC) are taken into account as auxiliary systems.

Winter season, mid-season and summer season identify different types of energy demands. The heat demand for space heating is present only during the winter season, the demand for space cooling is present only during the summer season. The demand for electricity for lighting and appliances and the thermal demand for hot water are present throughout the year.