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SciVerse ScienceDirect

Energy Procedia 14 (2012) 1386 – 1391

Energy Procedia

2nd International Conference on Advances in Energy Engineering (ICAEE 2011)

Optimization concepts in district energy design and management – A case study

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Abstract

The integration of optimization techniques in building and district energy design constitute an essential tool for reducing the global impact of energy services. Appropriate dynamic energy management systems must be employed too in order to maintain a high level of performance in the operational phase and to obtain better system knowledge. Therefore, in the strategic energy planning of districts, it is necessary to embody the main concepts of Smart Grid and virtual power plants frameworks. In the research presented, the preliminary results from a case study are illustrated with a reflection on energy consumption subdivision and load profiles for the sizing and operational strategy definition of distributed generation systems.

*Keywords:*Dynamic energy management; NZEB; Virtual power plants; District energy systems.

1. Introduction

Energy saving, carbon reduction and pollutant emissions reduction are priorities for the 21st century sustainable development. Smart Grid and distributed generation, in a medium/long-term perspective, may constitute answers to the pressing economic and environmental issues in the energy sector è [1]. Further, they can enhance the reliability, resiliency and security of energy infrastructures [2]. The Smart Grid, in particular, can become a decentralized infrastructure with embedded intelligence, built on the top of existing infrastructures, which will have to evolve in order to satisfy new tasks [3,4]. A wide spectrum of possible interventions has to be considered and polygeneration systems are a promising solution where a

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doi:10.1016/j.egypro.2011.12.1106

sufficient spatial energy intensity justifies investments in generation plant and distribution infrastructures (district heating and district cooling networks) [5].

Energy efficient building and districts rely on optimized solutions both for the project design and operational phase. The efficient dynamic management of energy demands, local generation plants, local distribution networks, national/regional grid and stochastic renewable energy sources is one key factor for achieving energy sustainability. For these reasons, models that can simulate and optimize the dynamic behavior of energy districts are today an important research field [6,7].

2. Optimization concepts for district energy design and management

Correct design principles themselves are not sufficient for guaranteeing high energy performance. Sustainable design protocols for buildings and neighborhoods must envisage operational verification of energy consumption. It is necessary to rethink the concept of monitoring and to integrate good design practices with the monitoring of energy flows [8], optimization strategies [9], uncertainty and sensitivity analysis evaluation [10].

2.1. Design of high efficiency/net zero energy buildings

Net zero energy buildings (NZEB) and energy efficient retrofitted buildings will be a core part of the medium/long–term strategy for energy sustainability. Building performance simulation models are essential for energy design. On the other hand, the analysis of energy performance of buildings via statistical and machine learning techniques [11] is a fundamental tool for planning processes and model calibration. The metrics used in general in the design process are subsequent: energy demand (end-use), primary energy (fossil, renewable, total), exergy, embodied energy. However, due to the high share of renewable energy sources, the problem of load matching and energy storage must be taken into account too in the design process [12].

2.2. Virtual power plants optimization

A Virtual power plant [13,14] refers to the ability to aggregate power production from a cluster of grid-connected distributed generation sources by a controller, typically a utility, and then to harmonize this generation with load profiles of individual customers. Therefore, the core function of virtual power plants optimization is to coordinate the production of distributed power plants in order to obtain the minimum cost of energy, satisfying the technical and environmental constraints. A tight integration between energy supply and demand can be obtained through demand response and storage technologies. The dispatch strategy is decided with one day ahead forecasting and continuously adjusted with respect to real-time operating conditions.

2.3. Design and management concepts integration

Energy efficient buildings and districts should be designed and managed by model based methods, elaborated within the specific project, in order to exploit the potential of technical solutions in economic, energy and environmental terms. It is necessary to have dynamic energy management systems to monitor continuously the behavior of the building/district and make informed decisions.

The general task for these systems is managing efficiently multiple energy commodities over arbitrary infrastructure topologies (networks), taking into account energy conversion, transport and storage. The specific tasks are: energy flows and system monitoring, real-time operation, short-term and long-term production planning and business evaluation. A short/medium term and a long-term vision of the key concepts for the implementation are given in the subsequent paragraph. A summary of the concepts is reported in Table 1.

2.3.1. Short/medium-term vision

As shown in different projects, the hourly and sub-hourly metering of electricity, gas and water is the first step to perform load forecasting and identify patterns in energy consumption [15]. The presence of a model of energy behavior allows the definition of model predictive control [16].

It is impossible to have full system integration up to individual components but continuous performance monitoring can improve the use of distributed generation technologies. Further, with additional information, it is possible to decompose energy consumption in its fundamental components [17] and analyze performance to program future interventions.

2.3.2. Long-term vision

In a long-term perspective, it is possible to think about the presence of a large quantity of embedded sensor within buildings and districts. The presence of sensors can transform them into decentralized complex systems. Acquired data will give a detailed vision of energy consumption patterns in buildings (occupancy, lighting, appliances, internal gains, solar gains, etc.) and will make it possible to have full integration of adaptive and predictive control principles (actionable intelligence up to individual sources and sinks) into the energy system which concretizes in effectively load management (scheduling, shifting, curtailment), energy conversion (unit commitment/economic dispatch) and storage.

Table 1. Vision of design and management concepts integration

Vision	Technologies	Analysis techniques
Short/medium-term	Advanced metering (electricity, natural gas and water)	Statistics and machine learning (time-series forecasting and pattern analysis)
	Distributed generation (CHP, PV, HP, etc.)	Optimization (economic dispatch, model predictive control)
Long-term	Advanced metering (electricity, natural gas and water) and sensor networks	Statistics and machine learning (time-series forecasting and pattern analysis)
	Distributed generation (CHP, PV, HP, etc.) and storage	Distributed complex systems analysis and agent based applications
		Advanced Optimization (integrated economic dispatch, load shifting, load scheduling and load curtailment)

3. A case study – The energy retrofit on an existing airport

The use of distributed generation technologies and the design of more efficient building are expected to rationalize the supply of energy to built-up areas [18]. Until now, however, only a few projects show full integration among DG and Smart Grid design principles at the district and building level. The case study presented is the energy retrofit of an airport in Veneto region, in northern Italy. This intervention constitutes the starting point for the planning process of the future development of the airport area.

The plan involves the evaluation of the performance of buildings and distributed local energy systems, with respect to economic, energy and environmental objectives. First of all, historical data series have been analyzed to identify the main characteristics, influencing factors and to calculate normalized typical daily load profiles for every month, reported in Figure 1. In particular, the techniques were used to calibrate load profiles with weather data files, in order to enable the coherent use of dynamic calculation tools for simulating heating and cooling load profiles. Load profiles, as well as energy prices and technical, economic and environmental constraints, will be the base for the next part of the research, which will involve the definition of distributed generation technologies to be installed (configuration and sizing), operational strategies and carbon and pollutant emissions (CO_2, NO_x, SO_2, PM10). The technical solutions adopted will affect the future development of the airport district, with a plan up to 2030.

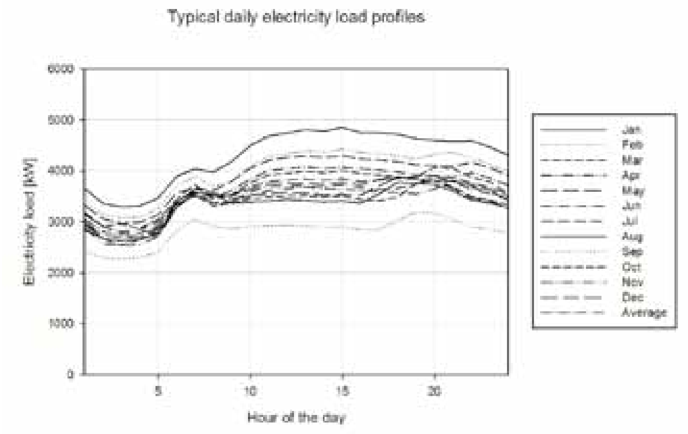

Fig. 1. Normalized monthly plots of typical daily electricity load profiles aggregated by month and averaged over the year.

Electricity consumption has been further analyzed to identify the incidence of the single end-use categories with respect to total consumption. Based on the subdivision, a retrofit hypothesis has been formulated. Retrofit measures and actual consumption are presented in Figure 2. The definition of the possible energy savings related with retrofit intervention is necessary to identify the related cost and, consequently, to take it into account in the global business strategy.

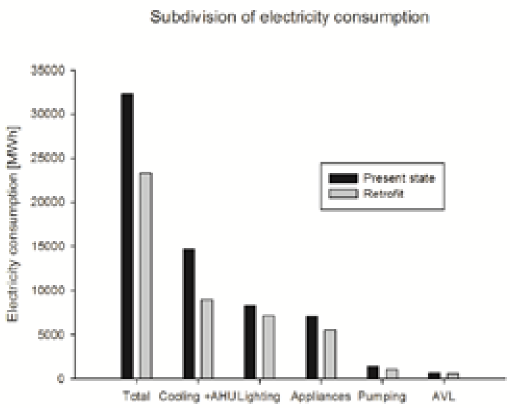

Fig. 2. Subdivision of electricity consumption according to end-use categories.

The peak power and the yearly energy demand for heating and cooling are reported for both present state and retrofit in Figure 3. As the graph highlights, it is possible to reduce cooling energy demand more than heating energy demand through a correct operational strategy, although cooling peak power can be reduced in a limited way without radical interventions.

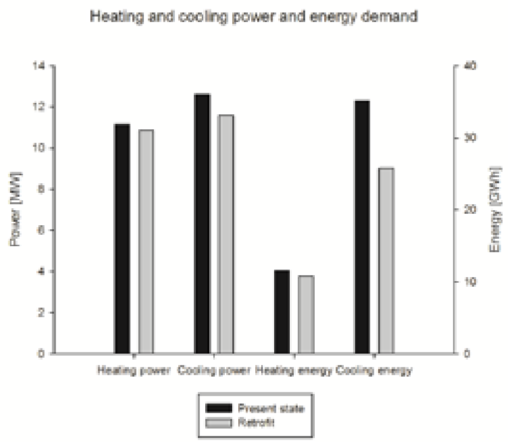

Fig. 3.Heating and cooling peak power and yearly energy demand.

As, this first part of the research involved the calibration of simulation tools with historical data series, it emerged that accurate forecasting is essential for automated model based decision methods, employed in dynamic energy management.

Conclusion

The development of models aimed at obtaining efficiency, reliability, resiliency and security of energy infrastructures in future districts is an important component of strategic energy sustainability planning. These models must not be used only in the design phase, but have to concretize in dynamic energy management systems able to perform various tasks.

In the definition of both energy efficiency requirements for new and retrofitted building and the configuration of a distributed local energy system (providing electricity, heating and cooling) to the area of Venice airport, optimization concepts have been considered. These principles deal with the integration of the advances in building energy technology and the Smart Grid and distributed generation paradigm and constitute the basis for a reflection which will affect the development of the area up to 2030 and beyond.

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