Distributed generation technologies for energy sustainability

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ABSTRACT

This paper analyzes some important aspects toward changing energy paradigma in urban area.
To that aim it is important to act synergically on three sides of the energy system:

- Demand side: by reducing energy demand;
- Supply side: by optimizing generation system and transmission of energy and by integrating local renewable energy sources also by distributed (co)generation, where it is possible;
- Management side: by implementing advanced management control systems able to reduce energy waste and to combine energy demand and generation in the best way.

Actions aiming demand containment can affect individual buildings or built systems, from the neighborhood to the metropolitan scale.
This paper includes a short survey of the currently available technologies for optimization of energy supply, focusing on the progress achieved by the technology in integrating renewable sources, (micro) cogeneration/trigeneration, distributed generation.
The work intends to demonstrate how the potential of these technologies is actually very high, but also to highlight the obstacles, not only technical, which are slowing down their diffusion.

KEYWORDS

Energy sustainability, Distributed generation, Energy planning.

INTRODUCTION

The analysis of environmental emergencies, population dynamics, energy demand trends, available energy resources, technology and financial issues reveals the possibility of the energy system collapse and the need of an energy revolution.
The urban neighborhoods could represent an optimal scale for promising energy strategy implementation. In this sense renewable energies, distributed generation, micro-cogeneration and micro-trigeneration are important opportunities.
However, there are still some problems to solve in the economic, regulatory and political-administrative fields. These barriers could be abated only when economic and financial issues will be no longer the only aspects taken into account and new energy systems will become economically more competitive.
Moreover, regarding the transition to energy optimized systems, two directions can be taken into account: the first one focuses on the single building and aims to make it energy self-sufficient; the other direction, characterized by higher level of complexity, aims to make not the single buildings but the whole city almost energy self-sufficient.

New technological progress lead to more and more self-sufficient buildings, however, on the other hand, it is possible to consider not merely individual buildings, but optimum size built environment served by neighborhood or urban scale micro-grids.
For the future, the second option seems to be the most promising: in this case technologies will use energy in a more rational and efficient way, bringing benefits also at the economic level.

RENEWABLE AND DISTRIBUTED GENERATION TECHNOLOGIES

The scenarios of future energy generation have to be based on high efficient technologies fuelled by different energy sources and will benefit from the high level of technological innovation achieved by the various components.
The definition of new models for energy supply and the evaluation of their technical and economic feasibility and applicability need to be supported by appropriate tools, not totally mature at the moment. A contribution in developing energy simulation models at urban scale represents probably the most important effort to that end.
Distributed generation (DG) is the basic element of the new energy paradigma due to its benefits like diversification of energy carriers and an intelligent use of renewable energy resources. City based on fossil fuels will disappear.
The research attempts to investigate system technology features, dissemination, maturity, economic aspects and application in urban area.
These considerations extend the analysis to the whole energy chain, from generation to distribution to storage, to end-use energy.
As a result of the technology review conducted, it is possible to notice the following aspects.

AVAILABLE TECHNOLOGIES

Technologies for renewable integration

The selection of renewable resources appropriate for urban energy systems is a hard task and needs deep analysis of local climate conditions, urban layout and utilities, environmental regulations and techno-economic conditions. In this work are considered the following renewable based systems:

- Solar systems: solar photovoltaic, solar thermal;
- Biomass systems;
- Ground source (in particular low-enthalpy) systems.

Solar photovoltaic

PV technologies are well known and continuously improving. Main barriers to large scale adoption of this technology are related to high costs and low intensity of the resource. In particular, in the urban area, it is not frequent to have available surfaces with appropriate geometric characteristics[1].The integration in the existing buildings, in any case, are more suitable rather than the construction of large photovoltaic fields.
Technological evolution, related to costs reduction, should lead solar photovoltaic system to economic competitiveness in the medium-short period. In particular, CdTe

[1] Shape, size, no shadow or obstructions to solar radiation.

technology seems to be particularly encouraging about this economic aspect. Furthermore there will be the development of technological storage devices, the simplification of procedures for grid connection, the development of micro-grids and/or the improvement of the grid performances.

Solar thermal

Solar thermal technologies are well known and there is no space for further improving. Also in this case, in the urban area, it is not frequent to have available surfaces with appropriate geometric characteristics[2] and the aesthetic problem makes these systems not always attractive. Moreover, technologies costs don't affect yet the economic competitiveness[3], when compared to the fossil fuels used in efficient thermal generation plants.
The problem of these systems is related to the time-lag between the solar radiation peak and the heat demand peak. This condition affects size and dimension of the solar plants, including the storage tanks. Thus, to make the system more efficient, two strategies are namely possible (but not ever suitable in urban environment): the first one is to build big plants with seasonal heat storage, the second one is to combine solar cooling systems, to partially satisfy cooling demand in summer.

Biomass

Biomass includes a large set of energy resources with different chemical-physical characteristics. Their uses, their conversion technologies and related dimensioning can be very different and refer to different levels of technological maturity and competitiveness.
As main suggestions and benefits, following points can be mentioned:

- The possibility of use large amounts of matter that, otherwise, would be wasted and/or treated.
- The need to refer to a limited area for the supply(local biomass).
- The possibility of creating new economic activities and land uses.
- The potential offered by considering the whole energy chain.
- The need to consider costs/benefits relating to other possible competitive uses of the environment (i.e. food crops).

The simplest systems are those that use biomass to supply heating and hot water.
Depending on the context, these systems can go from single-use stove (often in combination with solar thermal) to CHP biomass plants at neighborhood or at urban scale. Another CHP solution is represented by the ORC (Organic Rankine Cycle; i.e. by Turboden, Italy).

Geothermal systems

Geothermal energy can be exploited for different uses and it is possible to have high, medium, low and very low enthalpy system. In Italy, there are few areas where you can exploit directly high-enthalpy geothermal energy.
Among the possible uses of geothermal energy, ground source heat pumps (low-enthalpy system) for air conditioning and for domestic hot water generation seem to be very suitable in urban context.

[2] Shape, size, no shadow or obstructions to solar radiation.
[3] A part the contexts in which economic incentives are particularly favorable.

Despite of this, these systems are very expensive, especially considering the significant works of excavation to place pipes. Furthermore, other lacks are the absence of clear legal information and of indications about the soil characteristics.
Ground source heat pumps can be combined with electricity generation systems based on renewable sources (i.e. photovoltaic).

Mini-micro high efficient technologies

Cogeneration is the combined production of heat and power. The two type of energies are produced simultaneously with a single system: for this reason, compared with separate production, there is a more efficient use of primary energy. Nowadays, the size of cogeneration plants can be very small, permitting also to generate heat and power directly at home; this kind of application is very extreme. Applications in urban environment mainly concern micro CHP, with which, means the cogeneration plants that provide electrical power ratings of less than 1 MW_{el}.
Although there is a huge potential market for micro CHP, there are several obstacles to its spread, such as:

- Specific cost of small size solutions and cost of maintenance.
- Local emissions.
- Electricity generated enhancement.
- Regulatory limits and permits.

The technologies analyzed for the use of high thermodynamic efficient power generation systems are:

- Fuel cells.
- Internal combustion engines.
- Gas microturbines.
- Stirling engines.

Fuel Cells

The chemical energy transformation of a fuel into electrical energy can be directly carried out, similarly to what happens in ordinary batteries, through electrochemical reactions within the fuel cells (FC). Fuel cells can achieve efficiencies above 80% recovering the heat. There are different types of fuel cells: ones operating at low temperature, such as polymer cells PAFC and the PEM, and ones operating at intermediate or high temperature, such as the MCFC and SOFC.
Fuel cells diffusion is still rather limited. Obstacles to market penetration are high cost production, security (i.e. problems related to the presence of hydrogen), management terms and costs. Therefore it is very important to realize and test demonstration projects.

Internal combustion engines

Internal combustion engines are heat machines that generate mechanical energy through the combustion of a fuel-air mixture in a cylinder.
Engine sizes vary from tens of kW to a few tens of MW, it is possible to make plants of 100 MW using multiple units in parallel.
Recently, several models of small size internal combustion engines for domestic use have been widespread in the market, with sizes ranging between 1 and 5 kW_{el}. The

recent development is related to the liberalization of electricity markets and is made possible by the availability of electronic monitoring at relatively low cost.

External combustion engines (Stirling)

The size of Stirling engines is usually limited to a few tens of kW. Considering efficiency, Stirling engines are influenced by scale effects: the fact yield varies from 12-15% of power machine close to 1 kW_{el} up to 30-35% of machines of 50-100 kW_{el}. Currently, the most important applications of Stirling engines cover the following areas of interest:

- Concentrating solar plants with parabolic reflector.
- Electric generating plants operating at non-conventional fuels (biomass, waste production etc.).

However, the cost is rather high, and yields lower than those obtained with internal combustion engines haven't fostered a wide distribution of these devices.
Stirling engine has the advantage of not emit pollution and provide a noise reduced, at least when compared to the normal internal combustion engines. It is therefore the ideal solution for applications of distributed generation in the urban context.

Gas Microturbines

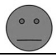
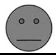
Microturbine is normally powered by natural gas and have an electrical efficiency of 14-16% (the addition of the regenerator leads efficiency between 25 and 30%).
Microturbines currently cover the field of electrical power between a few tens to hundreds of kW. Considering the electrical efficiency characterizing this technology, the convenience-related application of gas microtubine is closely linked to their co/trigeneration application configurations, able to fully exploit the production of heat during the entire cycle operation.
Microturbines are of suitable size for use in commercial buildings, hospitals or light industry with power draw of up to several hundred kW or cogeneration applications-only production of electricity.

CONCLUSIONS AND DEVELOPMENTS

The research was conducted to assess, in particular, the issue of distributed generation and of the applicability of innovative, high efficient and renewable based technologies in urban areas.
First applicability evaluations to urban scale (economic, technological maturity, security etc.) show that the most promising and suitable technologies are solar photovoltaics, solar thermal and microturbines. Solar photovoltaic and solar thermal, if properly integrated, can be well applied to the building in the urban context and it is expected, in a short period, that the price of the modules reaches adjustment of relative output to demand. Considering gas microturbines, the convenience of their application is closely related to their use in co/trigeneration configurations, able to fully exploit the production of thermal energy during the entire cycle of operation. Microturbines, in the medium period, can achieve significant cost reductions.
The urban scale applicability of biomass and fuel cells is still very difficult; biomass due to plant features problems, their location and management difficulties, supply and storage; fuel cells for costs still too high and low technological maturity. Biomass

plants are more suitable in non-dense urban environments and close to the source (i.e. district heating in mountain areas).
The following table summarizes, schematically, first preliminary results about the applicability of these technologies on an urban scale in Italy.

TABLE 1: Evaluation of technologies application

Technology	Cost	Application		
		Economic Aspects	Technological Maturity	Other
Solar photovoltaic	4-7 €/W_p			
Solar thermal	500-1000 €/m^2			
Biomass	5 €/W_{el} (1),(2),(3) 0,1 €/kg biomass			
Geothermal systems	1.200 - 2.500 €/kW_{th}			
Fuel Cells	2.000 - 6.000 €/kW			
Internal combustion engines	1.200 - 6.000 €/kW			
Engines with external combustion (Stirling)	1.200 3.000 €/kW_{el}			
Gas Microturbines	1.100 1.200 €/kW_{el}			

(1) Hypothesis of thermal treatment CHP plant with high-performance environment.
(2) Only investment costs.
(3) Benefits of heat recovery not considered

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