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Photovoltaics in Net Zero Energy Buildings and Clusters: enabling the smart city operation

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Abstract

From 2012 to comply with the ED 2010/31/EU and its recasts, all new buildings will perform as Nearly Zero Energy Buildings (NearlyZEBs). Buildings are going to be transformed through a careful design into energy generation systems, and the conventional, centralized system of energy generation is going to be replaced by a "web" of energy generation systems. Photovoltaics (PV) seems to be one of the most suitable energy generation technologies for enabling this change, thanks to its “fair” cost, technical features, and multifunctional use in the building’s envelope, as well as in the urban environment. PV will be an indispensable technology for Net Zero Energy Buildings (NetZEBs), with the consequence of being a kind of “ubiquitous” technology, also suitable for added uses than the traditional ones. For example: in addition to the multifunctional use in the building’s envelope, it might offer advanced services for improving the efficiency and participation in the city processes. A multidisciplinary investigation on possible ways for PV and NetZEBs to change the future urban scenario is proposed, focusing on design, energy management and technological issues to support a Smart City (SC) vision.

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Keywords: Photovoltaics, Net Zero Energy Building, Net Zero Energy Cluster, Smart City, Energy optimizer

1. Introduction

The wide use of Renewable Energy Sources (RES) has changed the energy scenario in recent years, and the European Directive 2010/31/EU is going to be the driver of an even more radical shift. A NearlyZEB is a high performance building that generate the energy it needs by using RES on site or nearby.[1] The building is therefore going to be transformed into an energy generation system, and its design should consider not only the traditional design aspects, but the energy and consumption aspects, too. One consequence of these likely changes, is that the conventional, centralized system of energy generation is going to be replaced by a "web" of energy generation systems, that would correspond to the

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physical pattern of the city itself (being the buildings of the future energy generation systems themselves). Moreover, the possibility of using nearby RES opens new research issues for the design of energy generation systems, not limited anymore into the building's footprint.[2] Further investigation is needed at least on two aspects: 1. the design of the physical form of the city, which shall consider the use of RES (and PV in particular) in its domain; 2. the energy web has to be managed in the appropriate way to ensure a good performance of the integrated energy networks, and the appropriate energy savings. Moreover, in such a new context, research questions arise on the use of PV: How can PV support and eventually drive the change from a traditional urban environment to a hybrid urban environment made out of buildings, energy, and communities, interacting with each other? What might be the technological possibilities and added value services offered by PV? What are the new research needs we should face in the next years? This study tries to give some first possible answers to these questions. In particular, firstly some issues related to the design of Nearly (or Net) ZEBs are addressed, with a special focus on PV. Secondly, the broad concept of "smartness" is discussed, mainly considering the role of PV technology and new services that this could offer the users (users: buildings, clusters, communities of people). Finally, some new research issues will be proposed as new topics to be investigated towards a smart city vision.

2. Photovoltaics, Net Zero Energy Buildings, Net Zero Energy Clusters: towards a smart city vision

In the past years, the use of PV for buildings has been envisioned as a suitable technology for reducing the electricity demand from the electric grid, and minimizing the use of new land, through the integration into the envelope. In relation to this, the ways PV can be used in a building's envelope have been described as two main options: BAPV (Building Added PV) and BIPV (Building Integrated PV); the use PV in relation to the building's envelope, from the formal and the technological points of view has been deeply investigated.[3] [4] A NetZEB is a building that reduces its energy needs thanks to efficient energy gains, and supplies the resulting low energy demand through RES, in order to get a Zero Energy balance between annual energy consumptions and energy supply. The term "Net" highlights the connection with the electricity grid overcoming limits of the current storage technologies.[5] [6]

PV can be considered a very relevant technology for designing NetZEBs; in particular, research carried out on a wide collection of case studies in the framework of the IEA SHC-EBC Task 40-Annex 52 demonstrated that PV was used in all of them, because of its energy potentialities and the possibility of using it into the building's footprint (envelope).[7] It is easy to demonstrate that in most cases (tall buildings, dense cities with shadowed envelopes) the energy demand of a building is high compared to the available building's envelope surfaces for PV. As a consequence, the only building's envelope surfaces are not sufficient to place the PV required for powering the building, and *nearby* use of PV has to be considered. With regard to the energy balance, there is a need to extend its boundary beyond the building scale, to move to the urban and landscape scale.

Within a certain boundary domain, buildings that are not NetZEBs as singles can perform to reach the ZE balance as a whole, thanks to buildings with a positive energy balance which can compensate such ones with negative balances. These considerations lead to the concept of Net Zero Energy Clusters (NetZECs). Within such innovative scenario the use of PV is certainly one of the most interesting elements to be investigated from the design perspective. Specifically, if on one hand new problems for the use of PV arise when considering a wider scale than the architectural one; on the other hands, PV might support the above-mentioned wider system, when new functionalities of PV modules are introduced. If PV is used in all NetZEBs, and these ones are part of our cities, PV systems can be envisioned as kinds of nodes of a wide web for enabling the city to have a better performance and interaction with the users (Smart City).

3. Net Zero Energy Clusters scenario: Photovoltaics potentialities and open issues

The realization of NetZEBs, and even more of NetZECs, requires the development of suitable devices able to guarantee variables sensing, measurement and control and data exchanges between energy production and consumers to adequately manage data and information to consequent actions decision. The above-described "web of PV" can be considered as a kind of infrastructure to conceive as a tool to support such a complex hybrid system made out of buildings, energy and users. Here we propose to use PV as an enabling technology, by using a controller as the "intelligence" of this system.

The proposal is a master/slave architecture characterized by a unique building centralized controller (master) and some microcontrollers (slaves) placed in correspondence to each single source/load, as shown in Fig. 1.

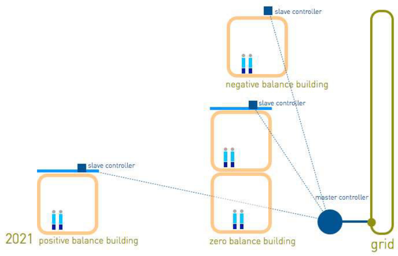

Fig. 1 PV concept for a Net Zero Energy Cluster. Image: A. Scognamiglio.

In the PV technology scenario distributed PV plant architectures are arising. They are characterized by N, series and parallel connected, PV generators controlled by means of dedicated modules DC-DC microcontrollers[8] [9] placed on the PV module back. Such devices are called Distributed Maximum Power Point Tracking (DMPPT) converters or PV Power Optimizer. Until now, designers' main attention has been focusing on the improvement of their performances by increasing efficiency and reliability and reducing costs. In fact, considering the efficiency aspect, any PV source shows a point of its output V-I characteristic where the delivered power is maximum. To reach the maximum efficiency, the Maximum Power Point (MPP), that changes as a function of the irradiance level and of the temperature of the modules, needs to be continuously tracked by modifying PV source working conditions. The use of switching DC-DC converters is commonly adopted for MPPT and to suitably link PV sources to loads.

3.1. Introduction of DMPPT converters in NetZEBs to a smart city vision

DMPPT converters can have an important role in NetZEBs. To get the Net Zero Energy balance, all the possible available surfaces (in the building's footprint and nearby) have to be used. So as, PV generators might be installed in not optimal position and/or inclination, suffering from shading effect and dust presence, with the consequence of operating in deeply not uniform conditions. In these cases, the introduction of a Power Optimizer, able to continuously track the PV module MPP to obtain the maximization of extracted energy, represents an attracting solution. DMPPT converters topologies and technologies are mature enough, and several solutions are already on the market.

3.2. PV Power Optimizer advanced NetZEC services

The above-described DMPPT devices represent promising solutions to realize NetZEBs slave devices. In fact, they could implement the MPPT function, and supplying additional features, such as PV plant variables metering and monitoring, data acquisition and communication services, fault diagnostic and alarm (fire, theft) functions. So as, it is possible to get both detailed information about the energy production and consumption and data exchange with other devices, buildings, users and management systems. In particular, if the master controller can have information about generation data and time and quantity of energy demand relative to every building loads, it can suitably match them together or it can require additional energy resources to reach the energy balance and to optimize the energy bill. This main controller can also recognize and adequately manage energy needs of uninterruptable loads or it can reschedule not urgent consumptions. These architectures can surely represent basic elements of possible NetZECs, as well as of future SC and Smart Grid (SG).

4. Conclusions

The new perspective introduced by the ED 2010/31/EU and its recasts turns PV from a technology useful for reducing the energy demand into a design parameter. In most cases in our cities, the energy balance boundary needs to be extended beyond the building's physical footprint considering a wider Net Zero Energy balance at the cluster level. Within the NetZEC, NetZEBs can be designed to perform as a whole and, in particular, PV can represent a fundamental role when designed as a "common thread" in the NetZEC able to create a "smart" connection among NetZEBs and the grid in order to reach the NetZEC target. Such goal seems to be achievable by using technology innovations represented by PV modules provided with new smart Power Optimizers. These are able to track the MPP, and also to provide information and advanced ancillary services, too. So as, a new research topic on PV, NetZEBs and NetZECs arises in order to envision an enlarged future urban scenario, considering both design and technological issues.

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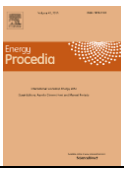

Biography

Alessandra Scognamiglio, architect, PhD in Architecture and Environment Technologies. Since 2000 researcher at ENEA on the use of PV in buildings. **Giovanna Adinolfi**, electronic engineer. Since 2010 researcher at ENEA on PV system design and power conversion systems. **Giorgio Graditi**, engineer, PhD in Electrical engineering. Since 2000, he is a researcher at ENEA and since 2011 he is the head of Photovoltaic Technologies Unit of ENEA. **Erika Saretta**, junior engineer from the University of Padua.