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Comparison of theoretical and real energy yield of direct DC-power usage of a Photovoltaic Façade system

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ABSTRACT

Multifunctional façade components have nowadays become a significant research topic as a step towards developing energy-efficient buildings. This paper presents the performance evaluation of an experimental setup of a real fully decentralized façade-integrated photovoltaic (PV) system installed in a prototype façade, for direct DC power use. The goal of this evaluation was to test the system's ability to fulfill a pre-designed daily electrical load of 925Wh corresponding to a three-people office space under 100% decentralization. This was achieved by studying the operation under different weather conditions and the impact of the system design and components on its overall output. The evaluation of both the actual and theoretical system outputs indicates poor actual system performance in terms of low energy yield and unacceptable load fulfillment factor, which did not exceed 0.95. At the same time it revealed underutilized system potential which could be exploited theoretically with a proper system configuration. The results in this paper conclude that decentralized façade integrated PV systems can completely satisfy their designated applications if properly-designed and implemented, and provides a methodology which could be used in designing similar systems. Satisfactory fulfillment is shown to be achieved by having 30% additional PV and 9 times bigger storage capacities in this system.

1. Introduction

So far, roof integration of photovoltaics has taken the bigger share in the BIPV (Building-integrated PV) system development, as it provides an optimized location for integrated PV systems. With its natural tilt, it results in higher energy yield and minimized visual disturbance [1]. On the other hand, the exploitation of roof surfaces sooner or later will not be enough to meet the increasing demand for on-site renewable energy generation and the European Union targets for nearly zero-energy buildings [2]. The buildings contribution to the overall CO_2 emissions reduction goals is one of the most essential parts in a way to decarbonize also communities and cities [3]. This clarifies the need for exploiting façade surfaces for solar energy harvesting which have a high potential for integrated solar technologies [4–6]. One should consider that one quarter of the total European BIPV area potential is contributed to building facades [7] in addition to the development of the European harmonized BIPV standard focusing on PV properties relevant to essential building requirements [8] The “Multifunctional Plug & Play Façade” Project (MPPF) [9] in Austria Fig. 1 was a key research project in this field. The project focused on multifunctional building façade components development, integration and pre-fabrication issues [10–12]. Recent international research projects including MPPF project, aim to develop new innovative concepts and prototypes of PV systems specially designed for building integration applications [1,13], where the PV system is not only used to generate electricity but to form a multifunctional element of the building envelope, able to fulfill numerous tasks such as day light penetration, glare protection, insulation and water tightness [14,15].

One topic of the MPPF Project was focused on decentralized multifunctional façade components. The measurement campaign presented in this paper aimed to directly utilize the power from PV modules in its DC form and without any connections to the grid, thus minimizing any power conversion losses. Considering DC distribution at the building level is proposed by some scientists to be an approach to improve the efficiency of power conversion [16].

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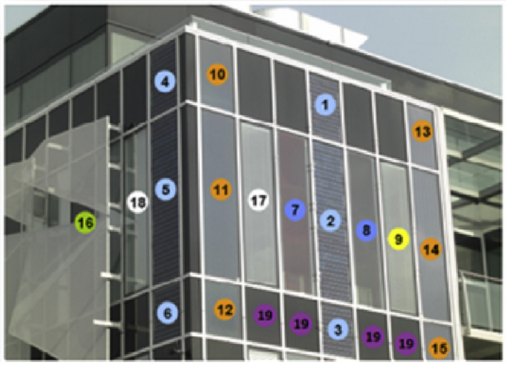

Fig. 1. MPPF demonstration façade.

DC building distribution may improve the power conversion efficiencies by using decentralized generation that can naturally or easily produce DC power. In fact, decentralized generation has seen a comeback in the last decades due to the global aims to improve overall energy use, besides the growing concerns about energy supply reliability, and concerns about reducing CO_2 emissions [17]. Some decentralized generation technologies such as PV and fuel cells naturally produce DC power which can be directly used as research showed. Using DC distribution can reduce PV system capital costs up to 25% by eliminating the need to use inverters and by increasing system efficiency in which a smaller PV array can provide the same electrical energy profile [18–20].

Fig 1 shows several components in the MPPF demonstration façade. In the opaque fields 1 to 3 and 19 (south facing) and 4 to 6 (west facing) the outer end panels were replaced by polycrystalline glass–glass modules with an anthracite enameling. The 4 polycrystalline glass–glass modules (19) have been used in the experimental setup presented in this paper. Two solar thermal collector fields (10–12 and 13 to 15) are integrated into the south facing façade and are connected in parallel to charge a hot water tank (500 L) via a controlled solar pump group. The tank provides hot water for the façade-integrated module for heating. Ventilation and air conditioning is provided by module 16 from LTG with a daily consumption of 600 Wh [21,22]. This module could be run by such façade PV system thus implementing PV cooling, ventilation and heat provision (where heating and cooling in the LTG were supplied by external hot and cold water supply) [23].

The experimental setup of the system under investigation provided data which was used to verify the performance of the system and to estimate the load coverage under various weather conditions throughout the year [11,12]. This paper presents the results as a proof of concept of a fully decentralized energy system that can supply is designated load continuously throughout the year. This is given through the evaluation of a full year including PV system and the system components, along with the analysis of the optimal functionality, the losses and the layouting of a 100% 365/365 supply system. The presented methodology can be implemented in future design of decentralized PV systems as it demonstrates and explains the main performance-influencing factors and challenges in system sizing and load supply.

This paper consists of the following main sections: an introduction to the used methodology is given in Section 2; results of the evaluation are given in Section 3, the system behavior is discussed in Section 4 and a final conclusion is given in Section 5.

2. Methodology

All evaluations presented in this paper were done for an experiment that was accomplished under the first stage of the MPPF project, dedicated to investigate the operational and multi-functional aspects of active building components and provide data for optimization [27]. In the presented work a decentralized façade-integrated PV system was examined. The methods used in the experiment were the following:

1. Load Modeling (see Section 2.1)
2. Experimental Setup (see Section 2.2)
3. Data Acquisition (see Section 2.3)
4. Data Processing and Analysis (see Section 2.5)

The experimental setup and measurement campaign was followed by an extensive analysis of the data. The approach of data treatment was in detail:

1. Solar resource assessment (see Section 3.2)
2. Energy yield evaluation (see Section 3.4)
3. Supply ratio and load fulfillment calculations (see Sections 3.5 and 3.6)

2.1. Synthetic load profile

Load modeling is considered to be essential for power systems simulation and analysis [28]. The way a load varies with time is represented by a load profile. Load modeling was used in this experiment to represent the electrical load for a small office space with an area of 25 m^2 for two to three people. The electrical load of this office consists of the following basic office appliances: general illumination, task light, laptops, telephone and a smoke detector, in addition to the following shared office appliances (in a common room shared between 15 small offices in total): water kettle, coffee machine, refrigerator, projector and a photocopier. A bottom-up approach was used in the load modeling by using the power requirement of each individual device (ex: main light or laptops) along with its estimated usage duration to calculate the total daily energy demand. Three different load profiles (scenarios) were designed for the purpose of testing the façade-integrated PV system under investigation. For all three the same method was used, but with an increasing energy demand of 371 Wh, 772 Wh and 925 Wh per day, respectively. The first two scenarios were covered