Applied Energy 142 (2015) 80–94

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Review

Photovoltaic self-consumption in buildings: A review

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HIGHLIGHTS

- Review of papers examining options for increasing residential PV self-consumption.
- Two main options: battery energy storage and demand side management (DSM).
- Higher potential for increased self-consumption with battery storage than DSM.
- Further research needed for a comprehensive view of technologies and potential.

ARTICLE INFO

Article history:
Received 3 July 2014
Received in revised form 3 October 2014
Accepted 12 December 2014
Available online 12 January 2015

Keywords:
Photovoltaics
Self-consumption
Household electricity
Energy storage
Load shifting
Demand side management

ABSTRACT

The interest in self-consumption of PV electricity from grid-connected residential systems is increasing among PV system owners and in the scientific community. Self-consumption can be defined as the share of the total PV production directly consumed by the PV system owner. With decreased subsidies for PV electricity in several countries, increased self-consumption could raise the profit of PV systems and lower the stress on the electricity distribution grid. This review paper summarizes existing research on PV self-consumption and options to improve it. Two options for increased self-consumption are included, namely energy storage and load management, also called demand side management (DSM). Most of the papers examine PV-battery systems, sometimes combined with DSM. The results show that it is possible to increase the relative self-consumption by 13–24% points with a battery storage capacity of 0.5–1 kW h per installed kW PV power and between 2% and 15% points with DSM, both compared to the original rate of self-consumption. The total number of papers is however rather limited and further research and more comparative studies are needed to give a comprehensive view of the technologies and their potential. Behavioral responses to PV self-consumption and the impact on the distribution grid also need to be further studied.

Contents

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http://dx.doi.org/10.1016/j.apenergy.2014.12.028
0306-2619/

1. Introduction

In recent years, the installed photovoltaic (PV) capacity in the world has rapidly increased. In 2013, PV capacity of more than 37 GW has been installed worldwide, adding up to a cumulative capacity of approximately 137 GW [1]. While the European share of the world PV market has declined from more than 70% in 2011 to 28% in 2013, Asia now makes up the largest share of new PV installations [1]. The growth of the PV market has led to a significant price drop of new installations, with an average PV system price decline of 6–7% per year since 1998 [2]. PV modules have faced the largest price drop in the last years and the global module price index is now less than $1 per W [2]. China is now the largest manufacturer of PV modules, with seven of the world's ten largest PV module suppliers [3]. The main reason to the Chinese dominance is the scale and supply-chain development [4].

The vast majority of all PV installations today are grid-connected [5]. Therefore, the PV production does not have to match the local consumption, in contrast to off-grid PV systems where the electricity production and storage have to match the consumption instantly as well as over a longer period of time. Traditionally, electricity is generated at large-scale power plants and distributed to the consumers via a network of high- and low-voltage transmission and distribution lines. Distributed generation, often intermittent such as small scale PV and micro-turbines, is often located closer to the consumers, resulting in a number of potential benefits such as reduced peak power consumption and increased power quality [6,7]. There are however challenges needed to be solved to achieve a high penetration of intermittent electricity production in the electric power system, such as frequency regulation, the ability to rapidly start and ramp the remaining electric power generation and better match the consumption with the intermittent generation to avoid exceeding voltage limits [8–10]. The latter case can partly be achieved with increased *self-consumption* of the distributed generation. Self-consumption is in this paper defined as the PV production consumed directly by the producer, which often is the owner of the PV system.

1.1. Brief overview of self-consumption policies and technologies

To promote PV electricity in the power system, support policies have been introduced in several countries to compensate for the gap between the costs of PV production and the revenue from utilizing or selling the PV electricity [11,12]. However, the cost of self-produced PV electricity is nowadays lower than the retail price of electricity in some countries, which makes self-consumption profitable without subsidies [5]. There exist several different incentives for renewable energy such as PV, for example feed-in tariffs (FiT), quota and trading systems, portfolio standards, tax credits and pricing laws [13]. In 2012, FiT schemes contributed to the largest share of the market incentives, but self-consumption is becoming a more important motive force [5].

The billing period is also an important aspect. The traditional definition of self-consumption states that PV electricity is consumed instantaneously or within a 15 min time frame [5]. Instead, so-called net-metering can be used to set off PV production over a longer period of time against the consumption, which means that the production can be "stored" in the electric grid and thus increase the self-consumption as recorded on the meter or the bill [5,14]. If net metering is used on a yearly basis, surplus PV production during the summer months can be saved to the winter months with surplus consumption or vice versa.

Germany has, since 2000, a comprehensive act for encouraging renewable energy, the Renewable Energy Act (Erneuerbare-Energien-Gesetz) [15]. Until 2012, there was a special bonus for self-consumed electricity, but since the FiT fell below the retail price of electricity, self-consumption has become profitable even without the extra incentive and it has therefore disappeared [5,16]. China has also recently introduced a self-consumption subsidy and Japan has a slightly higher feed-in tariff for micro-producers with self-consumption [5]. In the end of 2012, Italy also had a premium dedicated to self-consumption similar to the one in Germany, called V Conto Energia, whereas countries such as Denmark, the Netherlands, Belgium, Turkey and some US states have net-metering schemes [5,16,17].

There exist different technologies to increase PV self-consumption, where the two major ones are energy storage, mainly using batteries, and active load shifting, which is an important part of the concept demand side management (DSM) [18]. Depending on the revenue of selling PV generated electricity to and cost of buying electricity from the grid, increased self-consumption using these options or combinations of them can be profitable for owners of small-scale PV systems.

1.2. Aim and research questions

The aim of this review paper is to give an overview of PV self-consumption in residential buildings and to summarize results from previous papers within the field. Similarities and differences between the studies are presented and discussed. Moreover, the review paper forms a basis and gives suggestions for further studies of self-consumption from PV systems. The following research questions will be examined in this paper:

- How can self-consumption for a residential PV system be defined?
- What is the spontaneous self-consumption increase in response to installing a PV system in a household?
- Which methods exist to increase the self-consumption for a residential PV system?
- How much can the self-consumption be increased according to previous studies?
- Which are the identified knowledge gaps in the literature and what should be focused on in further research?

1.3. Outline of the paper

The outline of the paper is as follows: Section 2 will give an introduction on self-consumption and how to define it. In Section 3, previous research results on 'spontaneous' self-consumption improvement or change in energy use due to increased awareness, etc. will be presented. The different alternatives of increasing the