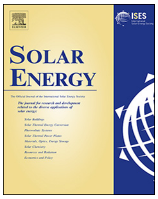
Solar Energy 170 (2018) 113–123

Contents lists available at ScienceDirect

Solar Energy

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



Optimal dimensioning of a solar PV plant with measured electrical load curves in Finland

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ARTICLE INFO

Keywords:
Photovoltaic power system
Optimization
Dimensioning
Profitability
PV
Nordic conditions

ABSTRACT

The amount of installed solar power in Finland tripled in 2016, reaching 27 MWp. In Finland there are no feed-in tariffs, and with the low price of electricity together with the annual distribution of insolation concentrating on summer, the photovoltaic electricity production is economical only when used for self-consumption. When the produced electricity is used for self-consumption, optimization of the photovoltaic power system size is essential for the profitability of the investment. Usually when optimizing the size of the PV system, the electricity production is optimized so that the electricity sold to the grid is minimized. However, this can lead to undersizing of the PV power system. The PV power system size can for example be dimensioned by using methods such as the minimum energy consumption of the building, the maximum power consumption, or the net zero principle. In Finland, the smart meters provide hourly consumption data from the electricity consumers, which can be used to generate electrical load profiles. These smart meters have been installed on almost every real estate.

In this paper, the profitability of a photovoltaic power system in the conditions of southern Finland is studied, simulated, and analyzed for self-consumption. Three cases, a grocery store, a dairy farm, and a domestic house with direct electric space heating, are presented and used in the simulation. Their electricity consumption is measured by hourly automatic meter reading (AMR) on a yearly basis. An Excel tool was used for the analysis of the electrical load profiles against the PV power system production at different system sizes. The profitability of the PV power system was studied by using internal interest rate, net present value, discounted payback period, and self-consumption rate. The effects of government subsidies on the profitability of a PV power system were also examined.

The optimized system sizes for the grocery store, dairy farm, and domestic house with direct electric space heating were 89 kWp, 28 kWp, and 5.2 kWp, respectively. The solar modules of the grocery store and the domestic house were facing south whereas the optimal module orientation in the dairy farm was 50–50% east-west. It was found that in the case of the grocery store and the dairy farm, the PV system size could be increased without the internal rate of return decreasing significantly, and thus, a larger system could be justified. Using the self-consumption ratio to optimize the PV power system size leads to undersizing of the system. It was found that the subsidies for the PV power systems have a significant impact on profitability. In the cases of optimized sizes, the grocery store would be economically viable even if the electricity price decreased annually by 3.6% with subsidies and 1.0% without subsidies. The optimized PV power system of the dairy farm would be economically viable if the electricity price decreased by 3.3% annually; however, without subsidies the electricity price would have to increase by 1.0% annually to remain viable. Considering a residential house, the annual increase in electricity price should be 0.6% with subsidies and 1.9% without subsidies.

1. Introduction

The use of photovoltaic (PV) power in the world continues to grow, with the global capacity reaching 303 GWp at the end of 2016 (IEA-PVPS, 2017). The installed capacity in 2016 reached 75 GWp with 35 GWp installed in China alone. China, America, and India are the top three contributors in the total installed PV capacity, accounting for 50% of the solar PV installed in 2016. In Finland, the cumulative installed grid-connected PV capacity tripled in 2016, reaching 27 MWp (The Energy Authority, 2017). However, this number is still low when compared to the PV potential of residential rooftops in Finland. Lassila et al. (2016) found that the PV capacity that could be implemented on

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https://doi.org/10.1016/j.solener.2018.05.058
Received 2 February 2018; Received in revised form 11 May 2018; Accepted 14 May 2018

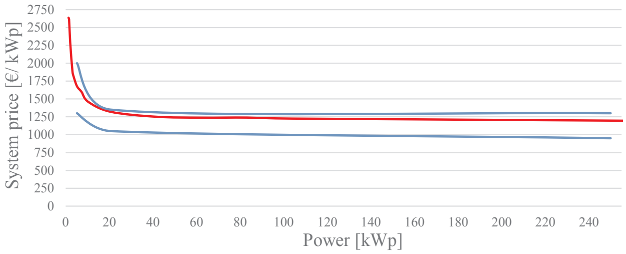

Fig. 1. PV system price cost per kWp in Finland with no subsidies. The red line indicates the data used in the example cases, obtained from 2015 (Korhonen, 2016). The blue lines represent estimations of some of the highest and lowest system price costs per kWp in Finland in 2016 (Ahola, 2017). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

residential rooftops could reach 12,000 MWp. This amount of PV installations could be adapted without a significant challenge for the electricity distribution system. The decreasing PV system prices in recent years are making solar power a more competitive and viable option in the residential and industrial sectors (IEA-PVPS, 2016). In Finland, the current system prices with no value added tax (VAT) are in the range of 1300–2000 €/kW in systems of 10 kWp (Ahola, 2017). Smaller system sizes are intended for residential houses. Larger systems for businesses and industrial buildings have a smaller investment cost per kWp because of the lower relative system costs. This is shown in Fig. 1. While the annual solar electricity production potential of southern Finland is around 850 kWh/kWp, the conditions of solar PV production in Finland vary at an annual level because of long days in summer and short days in winter (Kosonen et al., 2014). This leads to the annual distribution of insolation. However, long summer days with high insolation and relatively low average temperatures increase the potential of PV production, making southern Finland similar to northern Germany, where the annual solar power potential is around 900 kWh/kWp (Kosonen et al., 2014).

The PV power system can be sized for example based on the consumers load-profile, profitability, or self-consumption ratio. The self-consumption ratio indicates how much PV power production is used on site and how much is transferred to the grid. The PV power system can be sized by using the consumer's load profile so that the PV power production covers the minimum electricity consumption of the consumer (Mathews et al., 2015). This sizing method provides a high self-consumption ratio, because electricity is rarely sold to the grid. However, the system size varies depending on whether the base load of summer or winter is used when dimensioning a PV power system in the Finnish conditions; this can be seen in Fig. 2. The peak power demand or energy consumption can be used as a basis for the size of the PV power system (Marsan et al., 2015). The PV power system can also be sized based on the net zero concept, where the PV power production within a certain time frame, usually a year, covers the consumption of the building in which it has been installed (Sartori et al., 2012).

Matching the building load to PV production and considering the prices of buying and selling electricity affect the economic profitability of the system (Mondol et al., 2009). However, choosing the size of the PV power system only by optimizing its self-consumption can lead to undersizing and lower profitability of the system. This is because a larger PV power system has lower investment costs per kWp, or alternatively, a lower levelized cost of energy (LCOE) than a smaller system, as can be seen in Fig. 1. A larger system can produce more electricity for the self-consumption of the intended location than a smaller system, meaning less need to buy electricity from the grid. The PV system lifetime is considered to be 20–30 years, and a larger PV system could be chosen to anticipate a possible increase in the electricity consumption in the future. To improve the self-consumption and load matching of a sufficiently sized PV system, a battery energy storage system can be used to store excess energy produced during the day. Applying adjustable loads such as tank-type water heaters during peak production can also be used to increase self-consumption. The stored energy can then be used during periods of high demand or low production. While the price of battery storages is still high, implementing a battery storage to a PV system could be viable in the near future (Muenzel et al., 2015). Using a battery storage by participating in the electricity market as a frequency reserve or balancing power in residential houses could also be a viable option (Belonogova et al., 2016).

The objective of this paper is to use electrical load profiles with 1-h resolution and simulated grid-connected PV electricity generation to study the profitability of PV power systems for the example cases. Hourly electrical load curves and weather data from the city of Mikkeli in southern Finland were used in the simulation. A sensitivity analysis was performed on the profitability factors. Important factors that affect the profitability are solar yield, system design versus electricity consumption, investment costs, maintenance costs, cost of capital, and the price of electricity. In the calculations of this paper, the Excel tool developed by Korhonen (2016) was applied.

The outline of this article is as follows. First, automatic meter reading (AMR) is introduced and its opportunities and uses are presented. Then, the electricity retail prices in Europe and in Finland are presented together with the subsidies provided for PV systems in Finland. Next, optimization of the PV system is introduced and simulated, and the results are analyzed and discussed. Finally, conclusions are provided.

2. Solar PV policies and smart metering

2.1. Automatic meter reading

All of the cases studied in this paper are equipped with a smart meter, which is used to read hourly energy consumption data of the customer. The EU requires its member states to implement smart metering for the benefit of consumers by 2020 (European Commission, 2014). Finnish legislation provides that the DSOs have smart meters

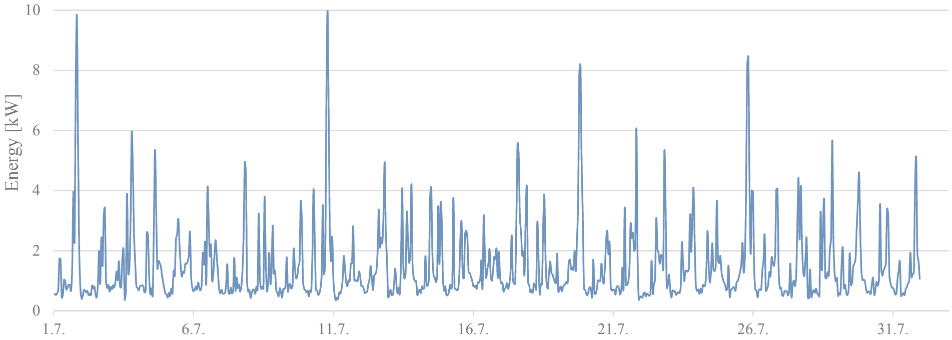

Fig. 2. Load profile from July of a typical Finnish domestic house with direct electric space heating. The annual energy consumption is 33 MWh.