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Simulation of a proposed novel weather forecast control for ground source heat pumps as a mean to evaluate the feasibility of forecast controls' influence on the photovoltaic electricity self-consumption

Richard Thygesen *, Björn Karlsson

Mälardalen University, School of Business, Society & Engineering, Box 883, 721 23 Västerås, Sweden

HIGHLIGHTS

- We simulated a building energy system with a GSHP fitted with a novel controller.
- We examine how the novel controller affects PV electricity self-consumption.
- The novel controller have a small impact on PV electricity self-consumption.

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ABSTRACT

The building sector in Europe and Sweden accounts for a large part of the total European electricity end use. A large fraction of Swedish buildings are equipped with heat pumps for heating and a combination of heat pumps and decentralized energy generation from photovoltaic systems is an interesting system solution for reducing the energy use. It is important that the building has a high self-consumption of the generated PV-electricity. Self-consumption can be seen as energy conservation and has a considerable higher economic value than exported electricity for the building owner.

A ground source heat pump with a novel weather forecast controller is simulated in Trnsys and compared to a reference case in regards to self-consumption and profitability. The economic analysis is based on the annuity method and a sensitivity analysis regarding annual cost, discount rate and annual electricity price change has been performed.

The results indicates that the increase in self-consumed photovoltaic electricity is limited to 7% with the proposed novel weather forecast controller, which means that the controller is unprofitable. Because of this the proposed novel forecast controller is not a viable way of increasing self-consumption in systems with photovoltaic systems and ground source heat pumps in Sweden.

1. Introduction

The building sector contributes to a large part of Sweden and Europe's total end use of energy [1,2]. The sector is expanding which will lead to even higher energy use if no actions are taken to reduce it. This challenge made the European Union to implement the directive on energy performance of buildings in 2002 and amend it in 2010 as a way of counter the risk of even higher energy use in the building sector in the future [3]. In the directive it is stated that for new buildings decentralized energy generation (DEG) from renewable sources and heat pumps should be considered amongst other considerations before the construction of the building begins.

To make DEG in the form of photovoltaic (PV) systems relevant and attractive for Swedish building owners a key issue is to make them profitable. The long term profitability of PV systems in Sweden are strongly dependent on self-consumption of the generated electricity. This will also be the case in the rest of Europe when the support schemes are lowered or ended. In Sweden the prize of a consumed kW h of electricity includes energy tax, sales tax, grid cost and energy cost. It is summarized to 11 €cent and the market prize of exported power is 3 €cent.

The current low electricity prices due to increased shares of mainly wind power makes the cost relation between consumed and saved electricity higher.

But a higher penetration of intermittent DEG might affect the electricity distribution network negatively with voltage problems [4,5]. Increased self-consumption and demand response open up the possibility of peak shaving and can lower the risk of overvoltage

* Corresponding author. Tel.: +46 21 103182; fax: +46 21 101480.
E-mail address: richard.thygesen@mdh.se (R. Thygesen).

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and reduce large quantities of surplus electricity in the low voltage part of the grid. This will in turn enable an even higher penetration of intermittent power sources.

In addition Sweden have a unique position with a high penetration of heat pumps in one-family buildings which can be used to increase self-consumption of generated PV electricity. A total of 690,000 air/water, exhaust air, and ground source heat pumps (GSHP) have been installed during 1992–2011 [6]. This means that around 35% of Sweden's approximately 2 million one family buildings have an air/water, exhaust air/water or liquid/water (GSHP) installed. The above factors make the topic of PV electricity self-consumption to an interesting and important research topic particularly for Sweden but also for the rest of Europe.

Extensive research on how to use heat pumps for demand response and peak shaving of intermittent and distributed power sources for residential buildings and on a larger scale have been carried out in recent years [7–10]. However the research have not been focusing on self-consumption of PV electricity but it has shown that heat pumps have a potential to shave power peaks in the distribution networks. This also makes it interesting to study the heat pump potential to increase self-consumption of PV electricity in buildings.

The research on how to increase self-consumption of PV electricity in buildings is picking up pace due to increasing interest in the field but is still a small research field [11]. The most influential studies into PV electricity self-consumption have been conducted by [12–14] in which demand side management in combination with storages has been used to significantly increase the self-consumption. Also the work in [15] has focused on further development of the system analyzed in [12,13] to include short time forecasting of irradiation and how demand side management affects self-consumption and forecast errors. The authors in [12–14] have investigated systems with electrical storage but have not included heat pumps.

Limited efforts have been conducted on system combinations of heat pumps and PV-systems and the studies conducted have been focusing on control systems for cost minimization [16,17], peak shaving [18], increased self-consumption [17,19–21] and increased self-consumption with the help of weather forecast control [22].

In [17] the authors have modeled a system comprising of a weather forecast controlled heat pump in combination with a battery storage and the authors have investigated two different control cases, cost minimization and PV-loss minimization. In the PV-loss minimization case no weather forecast is implemented. No consideration regarding heat pump operation or DHW comfort has been taken into consideration.

In [18] the authors investigated the possibilities with active control of the heat pump to increase self-consumption and to shave peaks with the help of thermal storage. Four different control cases for maximizing self-consumption by the means of a heat pump and two different energy storages was studied in [19]. The first control case utilizes only a thermal storage, the second utilizes only a battery storage, the third and fourth utilizes both energy storages but prioritize differently between them. All four cases are compared with a reference case where the heat pump is controlled by its normal controller and no battery storage is included. Their results suggest that self-consumption is increased between 1.5% (first control case) and 17% (third control case). The authors have not considered a weather forecast control and they have not investigated how the controllers affect heat pump operation and DHW comfort. Also in [20] a system with a demand side management controlled heat pump in combination with thermal and battery storages was studied.

In [19–21] no weather forecast control have been implemented as a way of increasing self-consumption of PV electricity. Furthermore the authors have not considered the controller impact on the heat pump operation and DHW comfort.

In [22] the authors have carried out research with forecast controlled air/water heat pumps as a way to increase self-consumption of PV electricity but the authors have a different approach than ours to how the heat pump heats the hot water storage tank in the system and the way the forecast controller is used to control the heat pump. Another difference between our work and the aforementioned article is that our work in this article is based on a commercial available GSHP with an internal hot water storage and that the novel weather forecast control manipulates parameters implemented in standard heat pump controllers as a mean to control the heat pump.

The main contribution of this work to new knowledge in the research field is the study of the feasibility of increasing self-consumption from a PV system with a weather forecast controlled commercial available GSHP-system in a one family building in cold climate (Swedish) conditions. This has never been studied in Sweden and to a small extent in Norway [22]. Furthermore we propose a method were the controller manipulates the conventional heat pump control.

Further scientific contribution in this work is the mathematical design of the novel weather forecast controller. Another important contribution is how a controller of this type affects the annual operation of the GSHP and the domestic hot water comfort (DHW).

All of the earlier mentioned articles in this section are based in different locations than the one in this article and have different levels of irradiation. None of them have investigated the possibility of a weather forecast control to increase self-consumption in residential buildings with heat pumps and PV-systems and simultaneously at the same time consider the controllers influence on heat pump operation and DHW comfort.

The main reason for evaluating a novel weather forecast control is to find what the controllers potential to increase self-consumption are. As stated earlier in this section it is important to make the PV systems attractive and long term profitable. Some of the above articles have been focusing on self-consumption without consider if there is a possibility to shift loads based on future forecasted irradiation values. This knowledge gap is important to bridge.

The following research questions will be answered in this article:

RQ1: How much will the self-consumption increase due to the weather forecast control of the ground source heat pump?
RQ2: How will the proposed controller affect annual operation of the ground source heat pump and domestic hot water temperatures?
RQ3: Is the weather forecast controller profitable?
RQ4: With the above research questions answered we make the overall issue: Is a weather forecast controlled ground source heat pump a feasible solution in terms of increasing photovoltaic electricity self-consumption in a one family building in Sweden?

2. Methodology

The simulation model developed and analyzed in [23,24] is the basis for all simulations and results in this article and is hereby referred to as the reference case. This model is complemented with the proposed novel weather forecast controller and two different storage tank sizes are compared to the reference case with regards to self-consumption. The controller is modeled in Trnsys via the program internal equation component.