East-South-West Orientation of PV Systems and Neighbourhood Energy Exchange to Maximize Local Photovoltaics Energy Consumption

Rosemarie Velik‡

CTR Carinthian Tech Research, Europastrasse 4/1, 9524 Villach, Austria

rosemarie.velik@ctr.at

‡Corresponding Author; Rosemarie Velik, CTR Carinthian Tech Research, Europastrasse 4/1, 9524 Villach, Austria, Tel: +43 (0)4242 56300 257, rosemarie.velik@ctr.at

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Abstract- Increasing local photovoltaics (PV) utilization can reduce energy transportation losses and mitigate overvoltages and transformer overloadings. Strategies so far investigated and applied for this purpose are load shifting, the use of electricity storages, and the installation of east-west instead of south-oriented PV systems. In this article, we investigate and analyze the potential of a novel concept for the purpose of local PV consumption maximization based on neighbourhood energy exchange in combination with different cardinal directions of PV systems installed on buildings within a neighbourhood. Results demonstrate that this novel concept can lead to significantly increased local PV consumption rates in relation to today's default configurations without considerable extra costs or control efforts.

Keywords Photovoltaics, east-west orientation, neighbourhood energy exchange, energy management, residential sector, energy self-consumption maximization, smart (micro)grids

1. Introduction

Within the last years, maximizing local photovoltaics (PV) utilization has been promoted in order to reduce energy transportation losses and to mitigate overvoltages and transformer overloadings [1]. In relation to household applications, measures currently actively discussed and investigated for this purpose are (1) load shifting, (2) the use of batteries, and (3) east-west oriented PV systems [2].

The basic idea of load shifting is the shifting of energy consumption to times when enough (PV) energy is available [3], [4]. The disadvantage of this approach is however a high control effort and the loss of flexibility for carrying out services, which is in many applications simply not acceptable [5]. An alternative is the use of battery storages for temporally storing surplus PV energy for later use [2], [6], [7], [8]. Disadvantages of this concept are however high investment costs and limited durability of storage devices. Furthermore, efficiency losses have to be considered as well as safety issues [9], [10]. Another approach is the installation of PV modules in east-west orientation instead of south orientation. This configuration has been found to have the advantage of a more even production curve throughout the day often better complying with consumption needs [11]. However, in order to avoid high mismatching losses, such installations usually require either two separate inverters for the two different cardinal orientations or at least an inverter with multiple maximum power point trackers [12]. This again signifies additional system costs.

In this article, we propose an alternative concept for increasing local PV energy consumption via non-south oriented PV systems and investigate its potential. Concretely, it is suggested to cluster PV-producing buildings to a neighbourhood. In this neighbourhood, each building has oriented its PV system in one specific cardinal direction (east, south, or west) therefore needing always only one solar inverter. To optimize local PV energy consumption within the neighbourhood, buildings can exchange surplus PV energy amongst each other. Such an energy exchange could either be realized via extra cable connections between buildings or – more cost efficiently – via an agreement with the grid operator to only consider the absolute amount of energy (purchased grid energy versus fed-in PV energy) coming from or going to the neighbourhood cluster.

2. Materials and Methods

2.1. System Configuration and Test Cases

Fig. 1 illustrates the system configuration used for the experiments carried out in this article. The system consists of 6 single family houses, each equipped with a PV system, loads, a connection to the main grid, and an interface to its neighbour buildings. The arrows in Fig. 1 indicate the principally possible directions of energy exchange between system components as far as they concern building 1. The same schema is applicable to the other buildings. The system topology was implemented using a Visual Studio C++ environment [13], [14]. To keep system modelling simple, efficiency losses of components were neglected in the experiments. This also allowed for a technology-independent analysis of the potential of our proposed local PV consumption maximization concept.

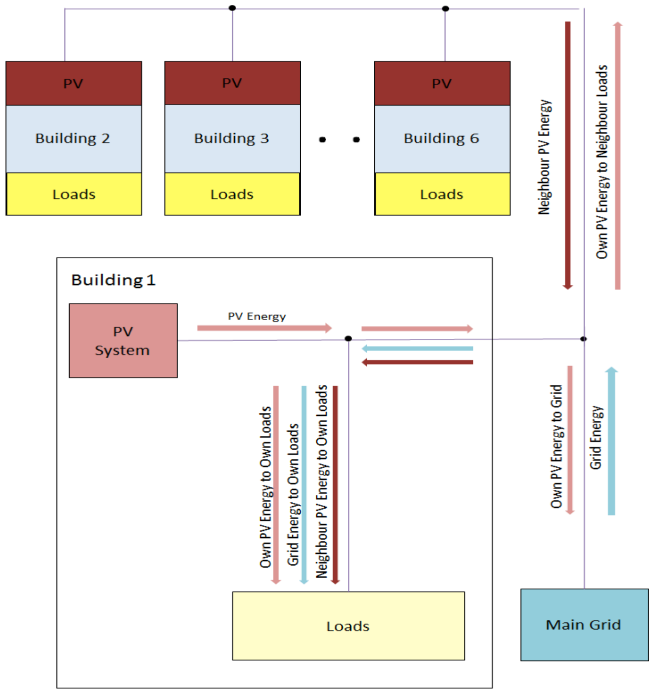

Fig. 1. Overview of system configuration and possible directions of energy flows between components

For the described system configuration, a number of different test cases were specified. The common objective of all test cases was the maximization of the local PV energy consumption within the neighbourhood. Parameters that were altered within the experiments were:

A. Cardinal directions of the PV systems

Experiments were performed for the following cardinal directions of the PV systems of the buildings.

- 6 South: PV systems of all 6 buildings oriented to the south
- 6 East: PV systems of all 6 buildings oriented to the east
- 6 West: PV systems of all 6 buildings oriented to the west
- 3 East, 3 West: PV systems of 3 buildings oriented to the east and of 3 buildings to the west
- 2 East, 2 South, 2 West: PV systems of 2 buildings oriented to the east, of 2 buildings to the south, and of 2 buildings to the west

PV modules were in all cases installed with a tilt angle of 30°.

B. Season of the year

Experiments were carried out for

- Winter: 4 weeks period in January
- Summer: 4 weeks period in July
- Season Average: the season average of the summer and winter period was calculated

C. Energy management strategy

Two different energy management strategies were applied to the test data:

- Individual: Each building had to maximize its PV energy consumption individually. PV energy could only be directed to its loads or to the main grid. Loads could only be supplied from the own PV system or from the grid.
- Neighbourhood: Buildings could additionally exchange surplus PV energy amongst each other for optimizing the PV supply of loads within the neighbourhood

2.2. Test Data

To perform simulations for the different test cases, PV production data and load consumption data had to be acquired for each building for a 4 weeks winter period and a 4 weeks summer period.

PV data were obtained using the S@tel-Light database [15]. For this purpose, recorded solar irradiance data for different cardinal directions with a surface tilt angle of 30° and a ground reflectivity factor of 0.15 were extracted from the database with an 1-hour resolution for the location Graz (Austria) for always a 4 week time window in January and July 2000. From these irradiance data, PV production profiles were generated by normalizing the irradiance data to yield an average production rate of 16kWh when averaging over the recorded winter and summer period:

$$P_{PV_j} = \frac{I_{S@telLight_j}}{\left(\sum_{k=1}^{n} I_{S@telLight\_Winter_k} + \sum_{k=1}^{n} I_{S@telLight\_Summer_k}\right)/2} \cdot 16\text{kW}$$

n … number of data entries for the 4 recorded winter/summer weeks (28 days · 24 entries/day = 672 data entries)

Load data were obtained using the ADRES-CONCEPT dataset [16]. From there, load curves from 6 Austrian households were extracted containing consumption data of a summer and a winter week with a resolution of 1 hour. Data were reproduced always four times to cover the 4 weeks test periods. Afterwards, these curves were normalized to yield an average load consumption of 16kWh per day over the 8 weeks summer and winter period:

$$P_{Load_j} = \frac{P_{Load\_ADRES_j}}{(\sum_{k=1}^{n} P_{Load\_ADRES\_Winter_k} + \sum_{k=1}^{n} P_{Load\_ADRES\_Summer_k})/2} \cdot 16kW$$

n … number of data entries for the 4 recorded winter/summer weeks (28 days · 24 entries/day = 672 data entries)

Table 1 and Fig. 2 give an overview about the average PV production and load consumption per household per day for the winter and the summer periods. As can be seen from Fig. 2, the normalization of the PV production and load consumption data result in equal energy production and consumption rates (16kW per building per day) when averaging over both seasons.

Table 1. Average load consumption and PV production per building per day [kWh] for winter and summer season and different PV orientations of the 6 buildings

		PV Orientation of Different Buildings				
		6 South	6 East	6 West	3 East, 3 West	2 East, 2 South, 2 West
Winter	Load Cons.	17.6	17.6	17.6	17.6	17.6
	PV Prod.	13.2	7.2	6.9	7.0	9.1
Summer	Load Cons.	14.4	14.4	14.4	14.4	14.4
	PV Prod.	18.8	24.8	25.2	25.0	22.9
Season Average	Load Cons.	16.0	16.0	16.0	16.0	16.0
	PV Prod.	16.0	16.0	16.0	16.0	16.0

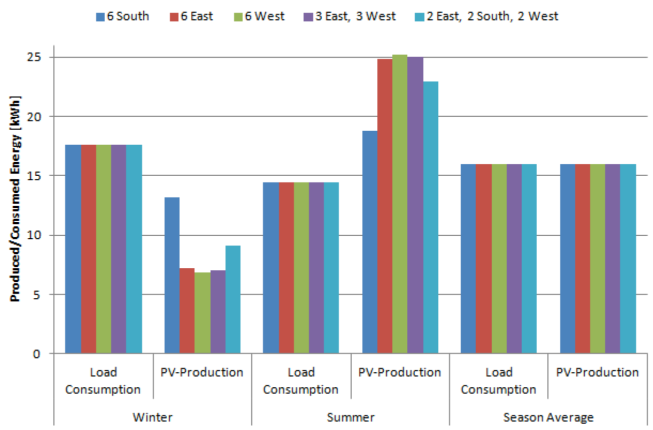

Fig. 2. Average load consumption and PV production per building per day for winter and summer season and different PV orientations of the 6 buildings

3. Results and Discussion

Table 2 and Fig. 3 illustrate the achieved amount of local PV energy consumption per building per day within the neighbourhood for the different investigated test cases. The most striking result from Fig. 3 is that, considering the season average, increased rates of local PV consumption could be achieved when executing a neighbourhood energy management strategy in a neighbourhood consisting of buildings with a combination of east-west or east-south-west oriented PV systems. For judging the remaining results of Fig. 3, further analyses were performed. Concretely, it was aimed to distinguish if observed gains/losses in local PV consumption derived from (1) the possibility to exchange PV energy between neighbours or (2) the alternative PV module orientations. For this purpose, the percentages of additional local PV consumption were calculated for the different test cases in relation to three different “base scenarios” described in the following sections.

Table 2. Average amount of locally consumed PV energy per household per day [kWh] in dependence of the season of the year, the PV orientation, and the employed energy management strategy

Season	Energy Management Strategy	Achieved Local PV Energy Consumption for Different Orientations of the PV Systems on the Buildings				
		6 South	6 East	6 West	3 East, 3 West	2 East, 2 South, 2 West
Winter	Individual	5.2	4.2	4.3	4.3	4.5
	Neighbour-hood	5.6	4.8	4.8	5.3	5.5
Summer	Individual	6.8	7.5	7.9	7.6	7.3
	Neighbour-hood	7.1	7.7	8.2	8.3	8.1
Season Average	Individual	6.0	5.8	6.1	6.0	5.9
	Neighbour-hood	6.3	6.2	6.5	6.8	6.8

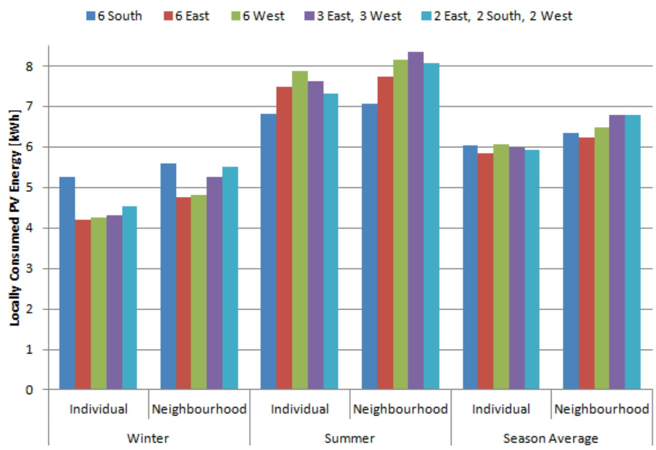

Fig. 3. Average locally consumed PV energy per building per day for winter and summer season and different PV orientations of the 6 buildings

3.1. Individual versus neighbourhood energy management

Figure 4 presents the percentage of additional local PV energy consumption of the neighbourhood energy management strategy in relation to the individual energy management strategy for the different analyzed cardinal direction of the PV systems.

$$p_{TestCase_{neighbour\_cd\_season}}[\%] = \left(\frac{E_{TestCase_{neighbour\_cd\_season}}}{E_{TestCase_{individual\_cd\_season}}} - 1\right) \cdot 100$$

p … percentage of additional local PV consumption per building and day

E … achieved local PV energy consumption per building per day

cd … cardinal directions of PV systems

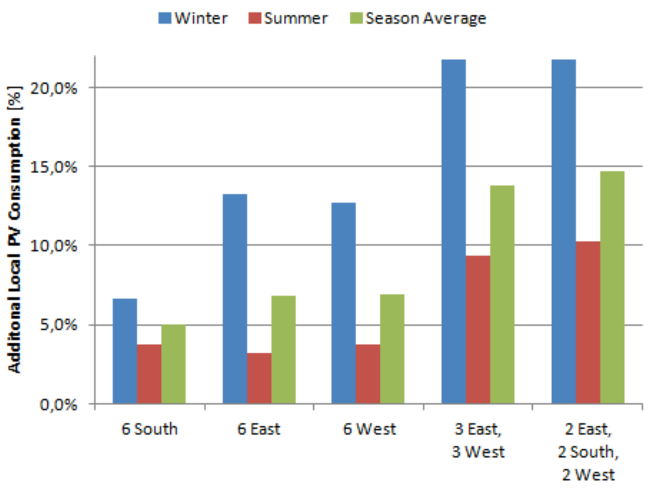

Fig. 4. Percentage of additional local PV energy consumption of neighbourhood energy management strategy in relation to individual energy management strategy for different PV orientations of buildings

As can be seen from Fig. 4, the energy exchange between neighbours brought in winter as well as in summer improved rates of local PV energy consumption. Results were most striking for the test cases of neighbourhoods with buildings of east-west and east-south-west oriented PV systems reaching additional consumption rates of 21.7% in winter and 9.4% and 10.3% in summer, resulting in a season average of 13.8% and 14.7%.

3.2. South orientation of PV modules versus other cardinal orientations for individual energy management

Fig. 5 illustrates the percentage of additional local PV energy consumption in the individual energy management scenarios (no exchange of energy between neighbours) for different orientations of the PV systems in relation to a south orientation of the PV systems of all buildings.

$$p_{TestCase_{individual\_cd\_season}}[\%] = \left(\frac{E_{TestCase_{individual\_cd\_season}}}{E_{TestCase_{individual\_6South\_season}}} - 1\right) \cdot 100$$

p … percentage of additional local PV consumption per building per day

E … achieved local PV energy consumption per building per day

cd … cardinal directions of PV systems

As can be seen from Fig. 5, in winter, a south orientation was clearly the best option for the individual energy management strategy. In summer, orientations including the cardinal directions east and/or west yielded 7.4% to 15.5% better results. However, averaged over both seasons, differences in results were lying only in the range of -3.1% to +0.5%.

3.3. South orientation of PV modules versus other cardinal orientations for neighbourhood energy management

Fig. 6 illustrates the percentage of additional local PV energy consumption in the neighbourhood energy management scenarios for different orientations of the PV systems in relation to a south orientation of the PV systems of all buildings.

$$p_{TestCase_{neighbourhood\_cd\_season}}[\%] = \left(\frac{E_{TestCase_{neighbourhood\_cd\_season}}}{E_{TestCase_{neighbourhood\_6South\_season}}} - 1\right) \cdot 100$$

p … percentage of additional local PV consumption per building per day

E … achieved local PV energy consumption per building per day

cd … cardinal directions of PV systems

As can be seen from Fig. 6, in winter, also for the neighbourhood energy management strategy, a south orientation of PV systems is the best option. In summer, orientations including the cardinal direction east and/or west yield 9.4% to 18.2% better results. Averaged over both seasons, differences in results lie between -1.4% and +7.4%. The highest benefits (7.4% and 7.3% additional local PV energy consumption) could be achieved in neighbourhoods consisting of buildings with east-west and east-south-west oriented PV systems.

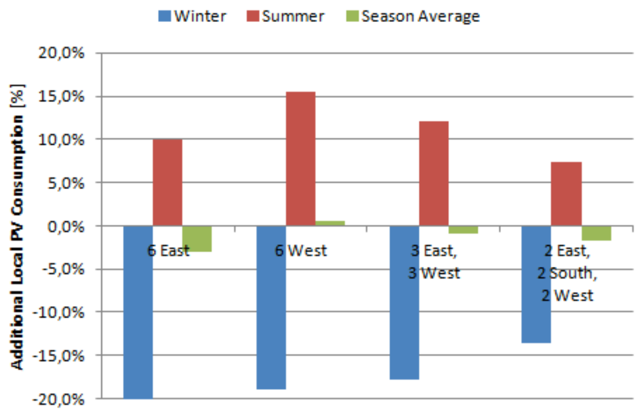

Fig. 5. Percentage of additional local PV energy consumption of different PV orientations of buildings in relation to south orientation when employing the individual energy management strategy

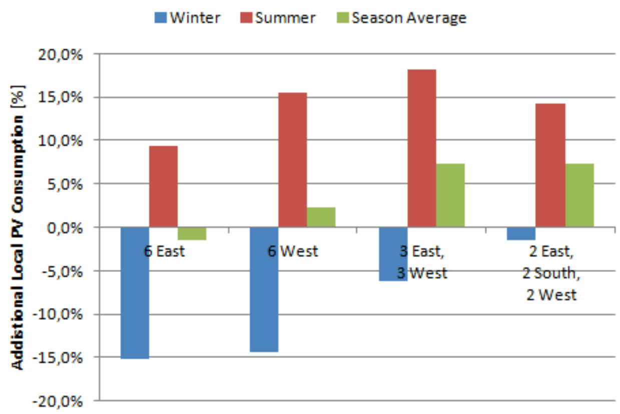

Fig. 6. Percentage of additional local PV energy consumption of different PV orientations of buildings in relation to south orientation when employing the neighbourhood energy management strategy

4. Conclusion

In this article, we analyzed the potential of east and west orientations of PV systems in addition or instead of south orientations within residential neighbourhoods in terms of local PV energy consumption maximization. Results demonstrated that, averaged over the year, no additional gains could be achieved in such alternative configurations when each building acted only individually. However, when buildings additionally exchanged surplus PV energy between neighbours, an interaction of buildings with east-west or east-south-west oriented PV systems led to significantly higher local PV consumption rates.

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References

[1] E. Vrettos, A. Witzig, R. Kurmann, S. Koch, G. Andersson, Maximizing local PV utilization using small-scale batteries and flexible thermal loads, EU PVSEC, 2013.

[2] M. Castillo-Cagigal, E. Caamaño-Martín, E. Matallanas, D. Masa-Bote, A. Gutiérrez, F. Monasterio-Huelin, J. Jiménez-Leube, PV self-consumption optimization with storage and Active DSM for the residential sector, Solar Energy, 85(9):2338-2348, September 2011.

[3] R. Velik, Cognitive architectures as building energy management system for future renewable energy scenarios – A work in progress report, IJSEI International Journal on Science and Engineering Investigations, 2(17): 68-72, 2013.

[4] E. Matallanas, M. Castillo-Cagigal, A. Gutiérrez, F. Monasterio-Huelin, E. Caamaño-Martín, D. Masa, J. Jiménez-Leube, Neural network controller for active demand-side management with PV energy in the residential sector, Applied Energy, 91(1):90-97, March 2012.

[5] R. Velik, G. Zucker, D. Dietrich, Towards automation 2.0: A neuro-cognitive model for environment recognition, decision-making, and action execution. EURASIP Journal on Embedded Systems, Special Issue on Networked Embedded Systems for Energy Management and Buildings, 2011:11, 2011.

[6] R. Velik, The Influence of Battery Storage Size on Photovoltaics Energy Self-Consumption for Grid-Connected Residential Buildings, IJARER International Journal of Advanced Renewable Energy Research, 2(6), 2013.

[7] G. Mokhtari, G. Nourbakhsh, A. Gosh, Optimal sizing of combined PV-energy storage for a grid-connected residential building, Advances in Energy Engineering (AEE), 1(3), 2013.

[8] R. Yu, J. Keissl, S. Martinez, Storage size determination for grid-connected photovoltaic systems, IEEE Transactions on Sustainable Energy, 4(1): 68-81, 2013.

[9] C. Jhu, Y. Wang, C. Wen, C. Shu, Thermal runaway potential of LiCoO2 and Li(Ni1/3Co1/3Mn1/3)O2 batteries determined with adiabatic calorimetry methodology, Applied Energy, 100:127-131, December 2012.

[10] W. Zhu, Y. Zhu, Z. Davis, B. Tatarchuk, Energy efficiency and capacity retention of Ni–MH batteries for storage applications, Applied Energy, 106: 307-313, June 2013.

[11] D. Staudacher, Efficient east-west oriented PV systems with one MPP tracker, 25th European Photovoltaic Solar Energy Conference and Exhibition / 5th World Conference on Photovoltaic Energy Conversion, 2010.

[12] M. Seyedmahmoudian, S. Mekhilef, R. Rahmani, R. Yusof, S. Asghar, Maximum power point tracking of partial shaded photovoltaic array using an evolutionary algorithm: A particle swarm optimization technique, Journal of Renewable and Sustainable Energy, 6(023102), 2014.

[13] R. Velik, P, Nicolay, A cognitive decision agent architecture for optimal energy management of microgrids, Energy Conversion and Management, 86:831-847, October 2014.

[14] R. Velik, P. Nicolay, Grid-price-dependent energy management in microgrids using a modified simulated annealing triple-optimizer, Applied Energy, 130:384-395, October 2014.

[15] S@tel-Light – The European Database of Daylight and Solar Radiation, Accessed: Sept. 30, 2013. [Online]. Available: http://www.satel-light.com/core.htm

[16] ADRES-Concept – Konzeptentwicklung für ADRES Autonome Dezentrale Regenerative Energie Systeme, Accessed: Sept. 30, 2013. [Online]. Available: http://www.ea.tuwien.ac.at/projekte/adres_concept/