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PHOTOVOLTAIC PLANT ORIENTATION STRATEGIES TO MINIMIZE GRID EXCHANGE IN FREE FIELD AND BUILDING INTEGRATED SETUPS

Philip Ingenhoven, Grazia Barchi, Marco Lovati, David Moser
Institute for Renewable Energy, EURAC Research, Viale Druso 1, 39100 Bolzano (BZ), Italy
*Phone: +39 0471 055634; Fax: +39 0471 055699; E-mail: philip.ingenhoven@eurac.edu

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Summary

High penetration of photovoltaic generation might lead to problems in the distribution grid such as instability, frequency deviations and reverse power flow. Parts of these problems can be mitigated by minimizing the exchange from and to the grid. A possible strategy to minimize the power injected into the grid and to maximize the power used to supply the load is to design a PV system in order to optimize the matching with the load. The classical strategy used in PV installation is to maximize the production. However, to address load matching, power maximization is not anymore the suitable approach. For this purpose, the aim of this work is to present two different strategies to optimize the orientation of photovoltaic modules. The first considers every possible orientations and no restriction on the surface area as possible in a free field installation. The second considers the surface of a building and tries to optimize the module orientations taking into account typical constraints from the built environment (e.g. limited area, shading from nearby building, etc).

Purpose of the work

The cumulative worldwide photovoltaic (PV) capacity is growing and in Europe alone has reached about 90 GW [1]. A study presents an analysis on the effect of large PV penetration on distribution grids using the energy consumption of different European countries [2]. A strategy that can support even higher penetration rates without investments in the current grid infrastructure could be an optimization of load matching by analyzing various combinations of PV orientation and inclination. Building integrated photovoltaic (BIPV) has been demonstrated to be a suitable solution for load matching as reported in [3]. This strategy will change if other objectives are considered i.e. module degradation, load matching, soiling, etc. The purpose of this work is to analyze the generation profiles of various PV configurations and see how these match the load profile.

Scientific innovation and relevance

The methods presented in this paper can help change the current paradigm from yield maximization to optimization. With the rising degree of PV penetration, the importance of grid servicing installation is getting obvious. As the price of storage solutions is still not financially viable, we propose strategies which may relieve the strain on the grid without the financial impact of storage systems. In this paper not only the energy solution is presented but also an economic analysis is presented. The algorithms and strategies developed in this work will help PV installers, grid planners as well as architects that are interested in BIPV solutions.

Results

The preliminary results for the free field analysis (*method A*) show that the optimal PV orientation is given by 90° tilted modules mainly installed facing east and west with smaller number of modules installed facing in southern directions. However this configuration is not feasible in an in urban context, where the surfaces are usually limited and the effects of shading by nearby buildings are not negligible. For that reasons a second analysis (*method B*) investigation introducing the restrains mentioned above was performed. The main results is that the optimal configuration depends on the ratio of the area available for PV installation and the load of the specific building. For a low load the optimal result does not differ much from the free field solution. However when the load is increased more and more southerly installed PV modules are necessary to meet the demand.

EXPLANATORY PAGES

Methods and preliminary results and conclusions

For *method A*, a year of meteonorm™ data of radiation and temperature were used to compute the PV production. The in-plane irradiation is reconstructed using the direct, diffuse and global horizontal irradiance. An array of possible tilt and azimuth angles from α=-90°(east) to 90°(west) of south for the azimuth and from β = 5° to 90° tilt angle (both in steps of 5°) is built in order to perform the optimization input. To compute the in-plane irradiance the following isotropic equation is used [4]:

$$G_\theta = G_D \cdot cos\theta + G_d \cdot \frac{(1+cos\beta)}{2} + \rho \cdot G_H \cdot \frac{(1-cos\beta)}{2}, \tag{1}$$

where θ is the angle of incidence, which itself is a function of time and is computed every 15 minutes. The angle β denotes the tilt of the module. G_D is the direct, G_d is the diffuse, and G_H is the global horizontal irradiance. The production is then computed for a polycrystalline module using the equations presented in [5]. The various parameters defined in [5] and used in this work were measured from a poly-silicon PV module in indoor measurements. To predict the temperature behavior correctly we used measured data from [6], where the Ross factor for a building integrated system using poly-silicon PV was found to be about K=0.03 °C m^2/ W. The power in each tilt/azimuth combination was normalized to an installed power of P_{Wp}=1kWp.

For each combination of tilt (β) and azimuth (α) the power vector $P_{\beta,\alpha}$ (in time with ΔT = 15 min) was found. As load profile, the residential consumption provided by the German electricity provider *westnetz.de* were used. The load profile is normalized to 1*MWh* of consumption which is a good approximation of the average residential electricity consumption per capita [7]. The optimization function is given by computing the difference between production and daytime consumption C every 15 minutes, like in the following equation:

$$\int dt \left|\sum_{\beta,\alpha} a_{\beta,\alpha} P_{\beta,\alpha} - C\right| = Minimum \tag{2}$$

the coefficients $a_{\beta,\alpha}$ indicates the power installed for each tilt and azimuth combination. The resulting non-zero coefficients are given in Table 1:

Table 1: coefficients result from the optimizations

$a_{\beta,\alpha}$	82.9	62.4	97.5	33.9	110.9
Tilt β	90°	90°	90°	90°	90°
Azimuth α	-90°	-30°	-25°	70°	90°

This result is remarkable that is favors purely façade installation and discards all other more efficient inclinations. In total 387.7 *Wp* have to be installed per person, which covers 64.6 % of the day time load and 36% of the total load. The same amount of PV installed following a yield maximization strategy with tilt: β=40° and azimuth: α= 20° west would produce 4.2 the amount of energy over the year, which would net cover 104.8% of the daytime load.

In terms of energy exchange with the grid the found optimum has minimal net exchange, whereas the maximally producing configuration shows a large over production especially in summer, which might cause problems to the grid. In quantitative terms we find that in the case of maximal production the over production during the day amounts to 37.6% of the daytime load whereas the demand from the grid amounts to 32.8%. In the minimal grid exchange case we find that the over production is massively reduced to only 5.4%, however the energy taken from the grid increases slightly to 40.8%. Figure 1 shows the difference between a maximal (red) and the optimal PV installation (green) in comparison with the load profile (blue).

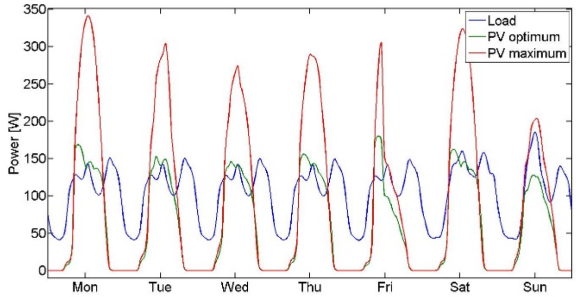

Figure 1- Difference between a maximal (red) and the optimal PV installation (green) in comparison with the load profile (blue) for a week in May.

Method B, considering the restriction due to a building integrated installation, is implemented in Radiance based Daysim [8] combined with a genetic optimization algorithm performed in Octopus [9]. Given a geometry for the building, the degrees of freedom consist in the possibility of varying tilt angle and percentage of coverage over each of the building's surfaces. For each combination (tilt east, tilt south, tilt west, quantity of installed PV in percentage for east, south, west) the power output of every hour in a year is calculated. The configuration is evaluated through the value:

$$f = \sum_{HOY} \left| P_{out} - Ab \cdot L_{person} \right|, \quad (3)$$

where f is the function to be minimized, *HOY* stands for hour of the year, P_{out} is the power output of the system in a specific hour of the year, and L_{person} is the average consumption for a single person described above and Ab is the number of inhabitants in the building. The value f is the power that has to be exchanged via the grid, either as consumption or as over production. Minimizing f will give the PV configuration with the best load matching, just as in *method A*. The main difference is between the two analyses is the use of RADIANCE [10] which uses ray tracing approach instead of the simple geometric approach of *method A*. This way local shading and the building geometry can be taken into account in detail.

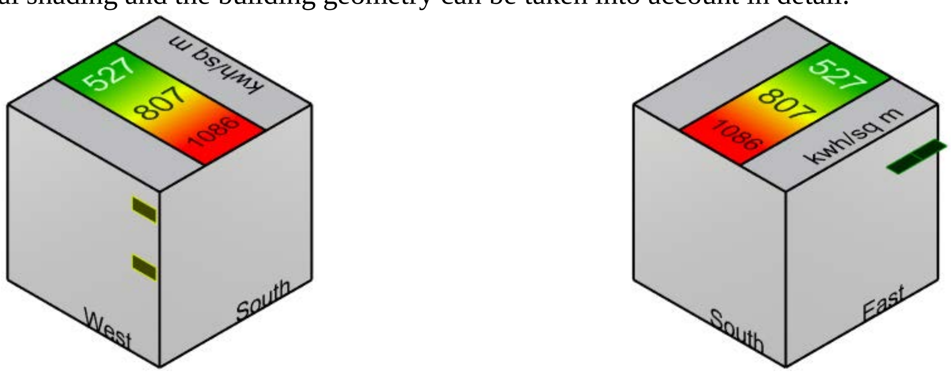

Figure 2- configuration of the PV module for the building occupied by 1 inhabitant. (ca. 0.8 kW_{peak})

The main result is that the optimal configuration depends on the ratio of the area available for PV installation and the load of the specific building, see Figure 2-4. For a low load the optimal result does not differ much from the free field solution. However when the load is increased more and more southerly installed PV modules are necessary to meet the demand.

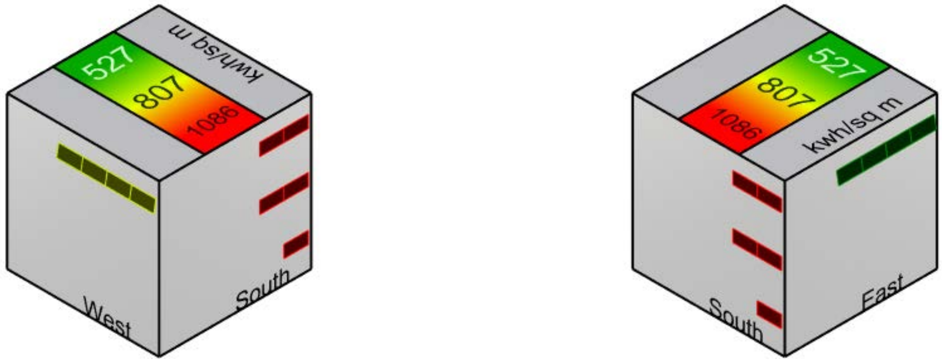

Figure 3-configuration of the PV module for the building occupied by 5 inhabitant (ca. 2.5 kW_{peak}).

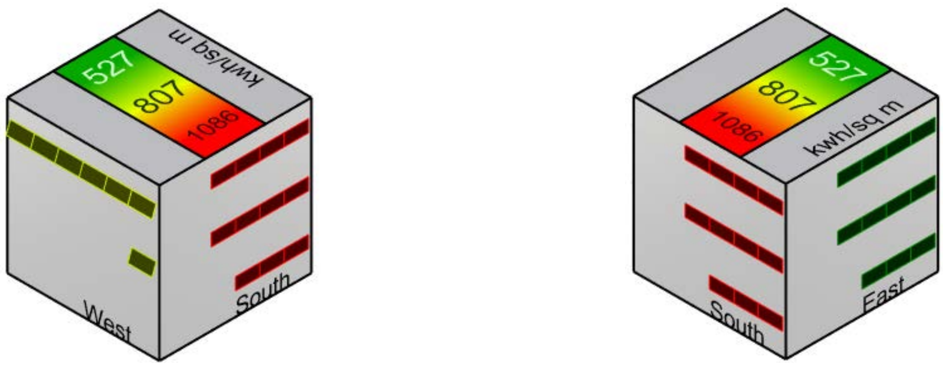

Figure 4-configuration of the PV module for the building occupied by 5 inhabitant (ca. 5.6 kW_{peak}).

Table 2 results from the optimization with method B

	west	south	east
1 inhabitants	Tilt 90° % 10	Tilt N.A. % 0	Tilt 0° % 10
5 inhabitants	Tilt 80° % 20	Tilt 90° % 30	Tilt 80° % 20
10 inhabitants	Tilt 70° % 40	Tilt 90° % 60	Tilt 90° % 60

REFERENCES

[1] EPIA, “Global market outlook for photovoltaics 2015-2019,” Jun. 2015.
[2] J. V. Paatero and P. D. Lund, “Effects of large-scale photovoltaic power integration on electricity distribution networks,” Renewable Energy, vol. 32,no. 2, pp. 216–234, Feb. 2007.
[3] W. Sprenger, Electricity yield simulation of complex BIPV systems, H. F.ISE, Ed. Freiburg/Brsg.: Fraunhofer Verlag, 2013.
[4] A. Padovan and D. Del Col, “Measurement and modeling of solar irradiance components on horizontal and tilted planes,” Solar Energy, vol. 84, no. 12, pp. 2068–2084, Dec. 2010.
[5] Yordanov, G.H., "Relative efficiency revealed: Equations for k1–k6 of the PVGIS model," in *Photovoltaic Specialist Conference (PVSC), 2014 IEEE 40th* , vol., no., pp.1393-1398, 8-13 June 2014
[6] L. Maturi, G. Belluardo, D. Moser, and M. Del Buono, “BiPV System Performance and Efficiency Drops: Overview on PV Module Temperature Conditions of Different Module Types,” *Energy Procedia*, vol. 48, pp. 1311–1319, 2014.
[7] http://shrinkthatfootprint.com/average-household-electricity-consumption Home Electricity Use Per Person 1157 kWh/year for Italy source: enerdata
[8] REINHART, Christoph; BRETON, Pierre-Felix. Experimental validation of Autodesk® 3ds Max® Design 2009 and DAYSIM 3.0. Leukos, 2009, 6.1: 7-35.
[9] http://www.food4rhino.com/project/octopus?etx
[10] WARD, G. RADIANCE reference manual. IEA SHC Task, 1996, 12.