PV System Design for Optimal Energy Production Based on Measured Data

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Abstract

One should always keep in mind optimizing energy and money gains while designing an integrated photovoltaic (PV) system for the client with electrical energy consumption. Any amount of electrical energy produced by PV system that is left after consumption, is given to distribution network. Given energy will always have lower price than electrical energy taken from distribution network. Therefore, PV system production size should be designed just to equal client consummation. If this is achieved, most produced energy compensates for energy that was supposed to be taken from distribution network. Consuming energy prices are always higher than receiving energy prices. In this research single consumer with PV system is designed using client courtyard, respectively to terrain possibilities. The client already contains two modules of PV system. Measured data is provided for period of 30 months as follows: classic consumer, consumer with one PV system module, and finally consumer with two PV system modules. The object of this research is to design the size of third PV system module just enough to ensure optimal performance for subject client energy compensation. It will also ensure the best prices achieved with energy given in distribution network.

Keywords

PV system, on-grid, energy management, optimized scaling

Introduction

When contracting an PV system energy trading with certificated energy supplier in Croatia, one will be given three standard options to choose from. These options are private household with self-consumption, business with self-consumption, or energy producer. Each of those options has its own advantages and disadvantages.

Following the rules of energy trading, especially money rules, one will try and take advantage of the contract option which suits him the most. For example, a client can abandon household with self-consumption option if he does not like variable monthly price calculations for extra energy provided from PV system and can take energy producer option. Or for example, clients can start a new company just to invest and consume PV system on private household on business options. Such examples are analyzed in (Petrović et al., 2023) and (Koprivanac at al., 2023).

1. Contracting options

A business with self-consumption option described in (HEP-ODS, 2023.) is planned for business consumption clients who want to upgrade its electrical installation with PV system in order to consume this produced energy on site at exact moment it is produced. Therefore, this kind of PV system is inserted somewhere inside the local electrical installation. In case of client consumption is larger than PV system production all electrical energy deficit will be compensated from local electrical distribution network. Energy taken from the network is counted independently on a single counter. In other case client consumption can be smaller than PV system

production, in which case client does not need to take any extra energy from the network but rather give electrical energy surplus into the network. Energy given to the network is counted independently on a single counter.

When trading energy, like in example of (Kamran et al., 2019.) taken from and given to the network, keeping in mind this is a business model, the first step is to charge client with entire taken energy for a full (client) buying price. Aspects of demand-side are presented in (Meyabadi et al., 2017.) and (Jabir et al.,2018.). Then a single unit price is calculated depending on contract rules and billed to client but charged to entire given energy to the network. This means that compensation of taken and given energy is done in money values, only after lover price is applied to given energy.

It is essential to distinguish PV system production from total energy taken from the network and total energy given to the network. All these energies combined are used to stably supply client energy consumption as shown in Fig. 1.

FIGURE 1: EXAMPLE OF CONSUMER WITH PV SYSTEM ENERGY FLOW
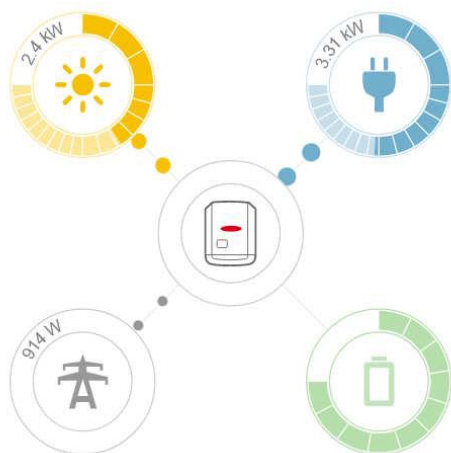
Izvor: www.solar.web

It is assumed that business clients regularly have significantly higher consuming prices for each spent kWh than private clients but often also have rather steady daily/weekly consumption curve and higher cumulated consumed energy. The advantage is that it is much easier to plan and has a higher percentage of consumed PV system energy. The disadvantage is that a reduced single unit price is applied on the entire given electrical energy to the network.

2. PV system upgrade to optimal performace

The client is a classic business consumer with consumption curves almost fixed for each day of the year, except one month in winter period used for cleaning and preparation for new season. During the entire 24-hour day consumption power is steady as there are many fixed consumption equipment (air conditioning / heating, ventilation, large kitchen, etc.), and have two spikes somewhere form 9:00 AM till 12:00 AM, and from 14:00 PM till 17:00 PM. PV system integration is contracted to three phases which allowed for better analysis of PV system energy production using measured data. Using measured data from the first two applied phases one can calculate PV system upgrade to achieve optimal PV system performance with client electrical consumption.

Client consumption data are gathered for 19 months previous to the first integration of PV system. This period contains data from January 2021 till July 2022. These data can be assumed as raw energy consumption.

The first phase is integration of PV system named SOLAR-1 which was done with 28 kW peak power of PV modules and DC/AC converter shown in Fig. 2. PV modules are divided into two roofs. The first part is 6 kW of PV module power with slope of 35° and second part is 22 kW of PV module power with slope of 10°. The azimuth for both parts is -30° (south-east). Measured data contains PV system production and local network energy counter with input and output for period from September 2022 till May 2023.

FIGURE 2: PV SYSTEM PHASE SOLAR-1

The second phase is upgrade of PV system named SOLAR-2 which was done with 20 kWp power of PV modules and DC/AC converter shown in Fig. 3. The azimuth of roofs used for PV modules is 45° (south-west) and slope of 10°. Measured data contains PV system production and local network energy counter with input and output for period from July 2023 till January 2024.

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FIGURE 3: PV SYSTEM PHASE SOLAR-2

3. Model of client PV system

The client is a single tariff consumer. Divided measured data for daytime and nighttime is only for purposes of this analysis. Measured data of current state is used to improve PV system energy production prediction. An improved model is then used to design a new phase of PV system upgrade named SOLAR-3. The object is to get optimized PV system power. As described earlier, in business with self-consumption option the best usage of produced energy is if it is used inside electrical installation at the time when it is produced from PV system. For this purpose, client consumption is divided into daily and nightly consumption even though the client has a single price for entire consumed electrical energy. This will set prime rule in design optimized PV system power upgrade as to get as little as possible produced energy in the network. The deficits energy consumption curve will have the same amount of produced and consumed energy from the network in spring and autumn, summer will have some surplus and winter some deficit in production. The yearly total should be zero. Analysis of SOLAR-1 and SOLAR-2 design model produced energy results and compare to measured data is used to extrapolate correction coefficients for design model.

In order to get more accurate PV system production data specifically for target location it is necessary to use measured data from existing PV systems, in this case SOLAR-1 and SOLAR-2. The main criteria of PV system upgrade planning and designing is total energy production, which should result in equalizing yearly energy consumption and production of client with PV system, which will give optimal price/cost performance. Since the measured data is available in terms of energy production, it is possible to use linear model on SOLAR-1 and SOLAR-2 data respectively.

In first step it is necessary to determine total yearly energy consumption deficit which is taken from distribution network. This will be target yearly energy for SOLAR-3 energy production. In second step, using SOLAR-1 and SOLAR-2 measured data, one can get improved prediction of SOLAR-3 energy production, which is presented as per kW of PV system peak power. These two results combined will provide peak power of SOLAR-3 using (1) where:

- E_{C2T} – total energy taken from the network with SOLAR-1 and SOLAR-2 online,
- E_{S12} – measured sum of energy production for SOLAR-1 and SOLAR-2,
- E_{S3U} – SOLAR-3 improved model energy production per 1 kW of installed PV power.

$$P_3 = \frac{E_{C2T} - E_{S12}}{E_{S3U}} \qquad (1)$$

Result PV system is sum all measured production data and improved SOLAR-3 prediction as in (2) where:

P_{SxM} – peak power of existing SOLAR-x

$$P_{PV} = P_{S1M} + P_{S2M} + P_{S3P} \qquad (2)$$

At the same time real data on total consumption is calculated as sum of PV system production and in/out energy flow from the network as in (3). Prediction of consumption for design of SOLAR-3 is done using all consumption data gathered from available measured period.

$$E_{CDx} = \sum_{2021}^{2023} \frac{E_{Cx}}{4} \qquad (3)$$

4. Results of PV system optimization

A comparison of prediction and measured data used in design of SOLAR-1 is shown in Fig. 4.

FIGURE 4: PREDICTED AND MEASURED PRODUCTION FOR SOLAR-1
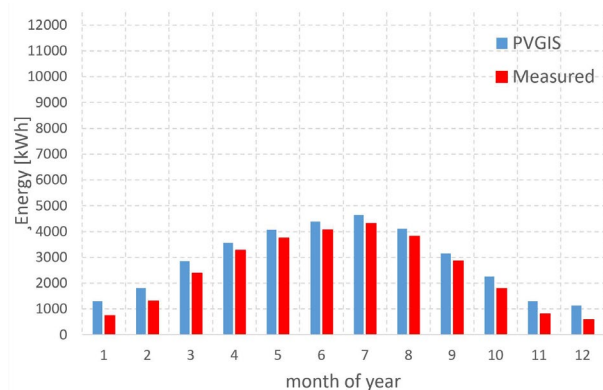
Same results are shown in Fig. 5. for SOLAR-2. Extrapolated corrections are shown in Fig 6.

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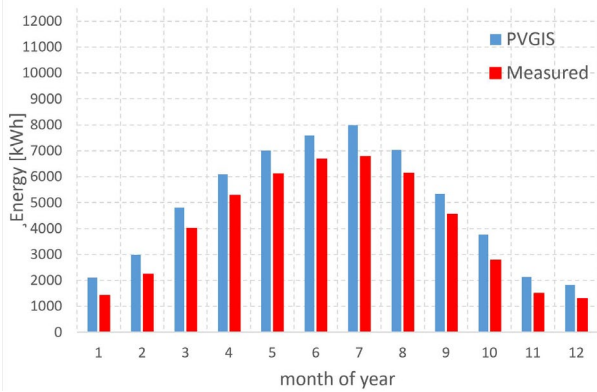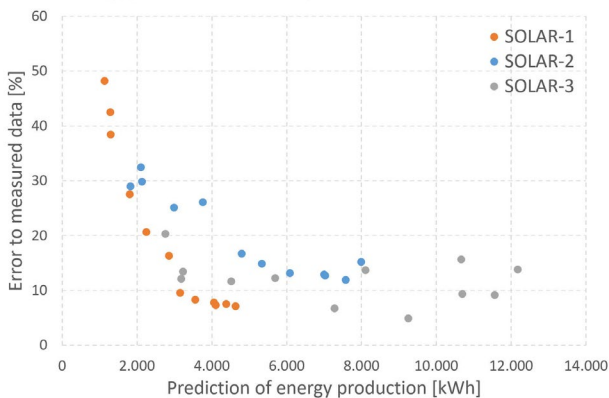*FIGURE 5: PREDICTED AND MEASURED PRODUCTION FOR SOLAR-2*

FIGURE 6: CORRECTION COEFFICIENTS FOR PV SYSTEM ENERGY PRODUCTION

Using this analysis, it is possible to extrapolate a new set of correction coefficients for design of SOLAR-3.

Combining all measured data, it is possible to present electrical energy flow between client consumption, PV system and the network, and it must be grouped in phases of PV system integration. These results are presented in Fig. 7., Fig. 8. and Fig. 9.

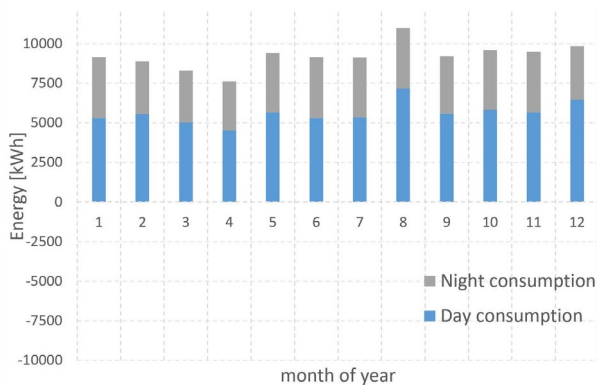*FIGURE 7: DISTRIBUTION NETWORK ENERGY FLOW FOR CONSUMER CLIENT*

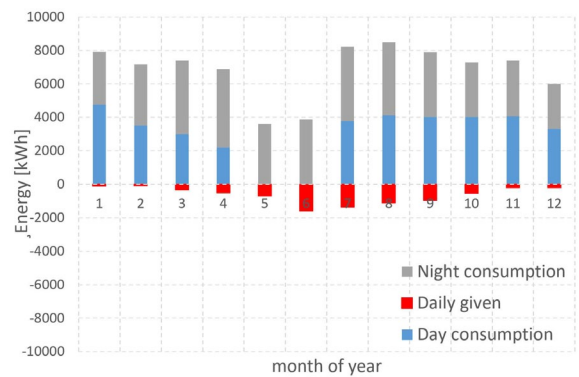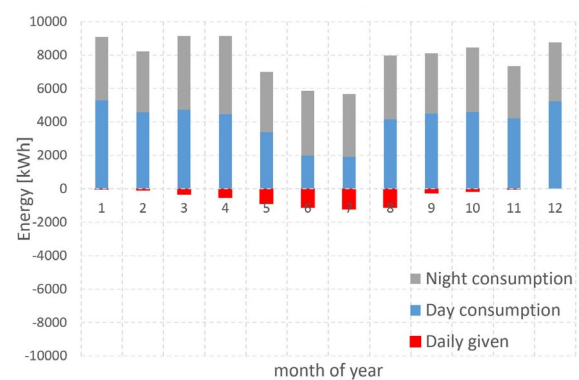*FIGURE 8: DISTRIBUTION NETWORK ENERGY FLOW FOR CLIENT WITH SOLAR-1*

FIGURE 9: DISTRIBUTION NETWORK ENERGY FLOW FOR CLIENT WITH SOLAR-2

When comparing results for SOLAR-1 and SOLAR-2, it can be seen that the client adjusted their consuming behavior in order to use as much energy as possible in the time it is produced. To do so, some other emergent are replaced with electrical ones, and some of energy tasks used to be done in nighttime by cheaper energy prices were moved to daytime.

The new PV system upgrade with SOLAR-3 is done in part of location which is basically the same geometry parameters as SOLAR-1 part 2. Defined as azimuth -30° (south-east) and slope 10°. Table 1 is input data for peak power of SOLAR-3 using (1).

*TABLE 1: INPUT DANA FOR SOLAR-3 POWER OPTIMIZATION*

	E_{C2T} [kWh]	E_{S12} [kWh]	E_{S3U} [kWh]
January	7911	1422	43
February	7156	2392	61
March	7397	3843	99
April	6880	4870	127
May	3600	5606	146
June	3870	6068	159
July	8220	6780	167
August	8490	6140	147
September	7890	4550	111
October	7290	2780	77
November	7379	1500	44
December	6000	1300	37
YEAR	82083	47250	1218

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When results from Table I. are used on (1) result is PV peak power of SOLAR-3, like presented in (4).

$$P_3 = \frac{E_{C2T} - E_{C2T}}{E_{S3U}} = \frac{82083 - 47250}{1218} = 29 \text{ kW} \qquad (4)$$

If the result of optimized PV system upgrade SOLAR-3 is implemented in improved model for electrical energy production, it is possible to add energy production prediction to measured data of client consumption, SOLAR-1 and SOLAR-2. Results are shown in Fig. 10.

FIGURE 10: CALCULATION OF DISTRIBUTION NETWORK ENERGY FLOW FOR CLIENT WITH SOLAR-1, SOLAR-2 AND SOLAR-3
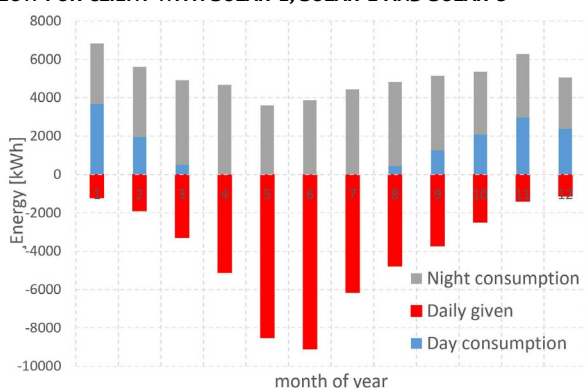
In order to get insight on what one can expect of optimized system, every kWh of energy production from SOLAR-3 should be first subtracted from daily consumption and if any amount of energy left subtract it from nightly consumption. Even though energy data is divided into daily and nightly consumption one must always keep in mind that client in this analysis is single tariff option. So daily and nightly consumption is only used to get better insight on energy consumption and production behavior, rather than have any impact on price distinction of presented energy data. Even when optimized, produced energy cannot compensate for nightly consumption without running through the network.

5. Conclusion

The design of the PV system consists of several aspects of dimensioning and placing elements on desired location. Some of them are technical, such as current client consumption, nominal power from the network, etc. At the same time there is geometry of location, such as free surface size of roof or land, azimuth, slope, etc. The financial aspect is also very important to client, so always should keep in mind price of investment and self-payment period. The PV system must be optimized for all aspects of client preferences to achieve best value for money. If done properly, like the example presented in this article for energy production aspect, PV system can be good investment. But if one fails to find optimal parameters while designing PV system, or not take all aspects into account, it can turn designed PV system into unprofitable investment.

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