# SELF-CONSUMPTION RATE ACHIEVED BY THE BIFACIAL EAST-WEST VERTICAL PV SYSTEM COMPARED TO THE CONVENTIONAL SOUTH FACING SYSTEM IN NORDIC CONDITIONS

Samuli Ranta[1], Joshua S. Stein[2], Hugo Huerta[1], Aleksi Heinonen[1], Erin Whitney[3]

[1]Turku University of Applied Sciences, Lemminkäisenkatu 30, 20520 Turku, Finland
[2]Sandia National Laboratories, Albuquerque, NM, USA
[3]Alaska Center for Energy and Power, University of Alaska Fairbanks, AK, USA
Email: samuli.ranta@turkuamk.fi

ABSTRACT: This paper presents a comparison between bifacial east-west vertical (EWV) and conventional south facing monofacial PV system in Nordic conditions. Special attention is given to the self-consumption rate reached at each system when residential loads are considered. Two test systems with bifacial EWV solar modules were installed, one on the rooftop of the premises at Turku University of Applied Sciences (TUAS) in Finland and another bifacial and monofacial system in Fairbanks, Alaska at the campus of the University of Alaska. System performance was monitored and recorded once per minute for post analysis. The real residential PV system at near proximity to the Turku test site was selected as a reference. The performance of the systems was monitored for a full calendar year in Finland and for two months in Alaska. This yield data is compared to the real-world residential load data collected earlier from the Turku region. As a result, the self-consumption rate of the systems can be calculated.

Keywords: Bifacial, Energy Performance, System Performance, Self-consumption

## 1 INTRODUCTION

Bifacial photovoltaic (Bifi PV) module technology has gained great interest in recent years as an effective way to improve efficiency of the PV system and decrease the levelized cost of energy (LCOE). Many studies have been conducted on the bifacial gain of such a system compared to the conventional monofacial system. [1]-[4]

In order to better understand the effects of different configurations, climates, and latitudes, several test installations have been built at different locations. TUAS did take part in the project in collaboration with the Sandia Bifacial PV Project (https://pvpmc.sandia.gov/ pv-research/bifacial-pv-project/) [5]. Systems under consideration in this paper have been installed within the scope of this project.

## 2 FIELD TEST SETUP

### 2.1. TUAS test site

The field test system shown in figure 1, consisting of four Bifi modules, was installed on the TUAS rooftop in Turku, Finland (60°N) in June 2017. Module specifications are listed in table I. The system was installed to the in-house developed aluminium racking that is designed to give as little shading for either side of the modules as possible.

The roof surface is bituminous membrane which is a common water tight layer used on commercial rooftops in Finland and whose albedo is very low, only about 0.05. Low albedo does not give the bifacial system any advantage when ground reflection is considered. At wintertime when there is snow cover, as seen in figure 2 from Alaska, much higher albedo and bifaciality is however expected. [2]

### 2.2. University of Alaska test site

The test site in Fairbanks, Alaska USA (64°N) was installed at the end of 2018 and was commissioned in June 2019 in time for the daylight season (figure 2). The system consists of bifacial and monofacial PV modules positioned at two different orientations (EWV & South-facing latitude-tilt) installed over grass.

There are two bifacial modules in the EWV configuration and two each of bifacial and monofacial at latitude tilt. Arrays are designed to minimize direct shading, and each module is attached to a microinverter and separately monitored for DC current and voltage.

**Fig. 1:** Bifacial EWV test setup on the rooftop of the TUAS facility in Turku Finland (60°N). Apartment buildings generate some late evening shading for test system during the summer months.

**Fig. 2:** The test site in Fairbanks, Alaska USA (64°N).

2.3. Reference PV system in Finland

The reference system is a real residential rooftop PV system located at a distance of 1.4 km from the TUAS test site. This system has 2.5 kWp power with very favorable shading conditions and has been in operation since summer 2017. Details of the system are given in table I.

**Table I:** Reference system and two bifacial test sites.

| Location | Turku, Finland 60°N | Turku, Finland 60°N | Fairbanks, Alaska 64°N |
|---|---|---|---|
| | Monofi S | Bifi EWV | Bifi EWV |
| Module type | Kingdom Solar | Prism Solar | SunPreme |
| Wp | 250 Wp | 295 Wp | 295 Wp |
| Tilt angle | 45° | 90° | 90° |
| Azimuth | 168° | 90/270 | 90/270 |
| Ground Surface | - | Bituminous membrane | Grass |

2.4. Measurement system

Each module is connected to the DC/DC optimizer which will maintain module level Maximum Power Point (MPP) tracking. DC voltage, current and power are measured between module and optimizer by a DC energy meter. Accuracy of this meter has been verified in-house and is better than 1 %.

The test system is grid connected with an inverter and operates as a normal photovoltaic generator. Relatively little shading is present at the location of the installation. There is, however, some shading in early summer mornings from nearby trees and from some far-distant apartment buildings in the evening (figure 1).

In addition to the DC measuring system, the temperature of each module is measured by a T-type thermocouple glued to a glass surface between the cells. Reference solar cells are also installed on the middle section of the racking, one facing east and one west. Thermocouple and monitoring cell signals are acquired by industrial distributed I/O modules.

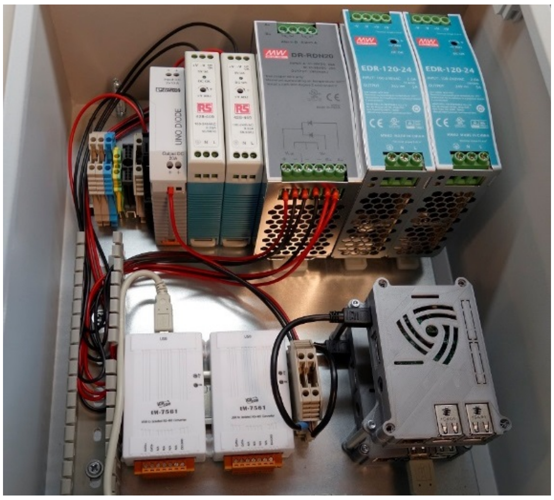

**Fig. 3:** Data collection system with two Raspberry Pi minicomputers and redundant power supplys.

2.5. Data collection

The DC values from DC energy meters of each module, along with the temperature, are acquired once per minute and saved to the database. The irradiation level from the reference cells is acquired once per second and the average value is saved to the database once per minute.

Data collection is implemented by two Raspberry Pi minicomputers connected to the energy meters and industrial I/O temperature modules by Modbus RTU (figure 3). Once collected, and averaged if necessary, the data is saved to the MySQL database located in-house.

The reference monofacial PV system data are measured by an inverter and acquired by a commercial photovoltaic monitoring system. Time resolution of this system is 5 minutes.

## 3 RESIDENTIAL LOAD PROFILES

For the electrical energy consumption of a residential house, it is typical that high loads are in the morning (breakfast loads) and in the evening (dinner loads), while during the mid-day there is period of low load (figure 4). This is one of the challenges when aiming for high self-consumption rate of photovoltaic energy, as the sun provides the highest amount of energy around noon, in the middle of the day.

In order to calculate a self-consumption rate for the system under research, typical residential load profiles were created. This was done by combining several one year hourly consumption profiles collected at an earlier SOLARLEAP project implemented by TUAS.

Consumption profiles used were those that were collected by a Distribution System Operator (DSO) for billing purposes. Higher resolution data would have been desirable but is not measured by DSOs at the moment. This type of data is also considered to be highly confidential, which presents special challenges for collecting large amounts of data.

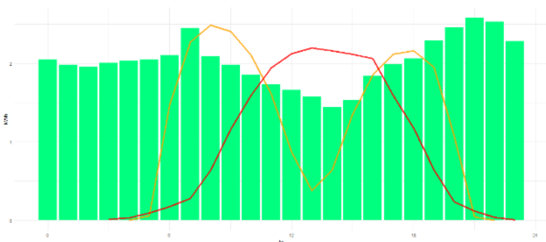

**Fig. 4:** Representative TUAS bifacial (yellow bimodal curve) and monofacial (red single modal curve) PV production profiles compared with an example residential load profile show in green bars. The x-axis is hours of the day going from 0 to 24. Values on the y-axis are power.

## 4 ENERGY YIELD ANALYSIS

The energy yields of the systems were calculated and visualized in an RStudio environment. In February, the bifacial EWV system already generates peak production at approximately 75% of the nameplate power, which is most likely the result of the high albedo from the snow. It is also notable that, during this time of the year, ordinary monofacial modules can often be covered by snow at this latitude, and their production would be zero in this state. The bifacial EWV system, on the other hand, is free from snow cover due to its vertical configuration, as seen in figure 2.

A Power vs Energy plot in figure 5 hand shows that the Bifacial EWV configuration does have a higher percentage of energy harvested than the south-facing monofacial configuration - around 50 Watts, which is the result of better performance in diffuse overcast radiation conditions.

The specific energy yield of the TUAS Bifi EWV system was 1.11 MWh/kWp, and respectively 1.06 MWh/kWp for monofacial South reference system. This result confirms that the systems generate an equal amount of energy for reliable self-consumption rate comparison.

The Fairbanks, Alaska test site was fully commisioned in June 2019, and initial data analyses has been conducted to date. Calculation of meaningful self-consumption rate requires a full year of data as a minimum, so analyses of Alaska site self-consumption rate will be completed in the future.

The first analysis of calculated daily bifacial gains for the Alaska South facing latitude tilt system are illustrated in figure 6. The green line is the scaled daily insolation which is inversely proportional to bifacial gain, meaning that bifacial gain is highest on cloudy and overcast days, which was also seen in TUAS data in figure 5.

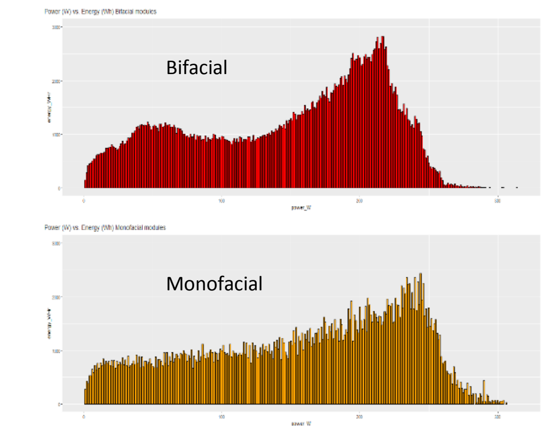


**Fig. 5:** EWV bifacial and south-facing monofacial Power vs. Energy plot of the Turku test site.

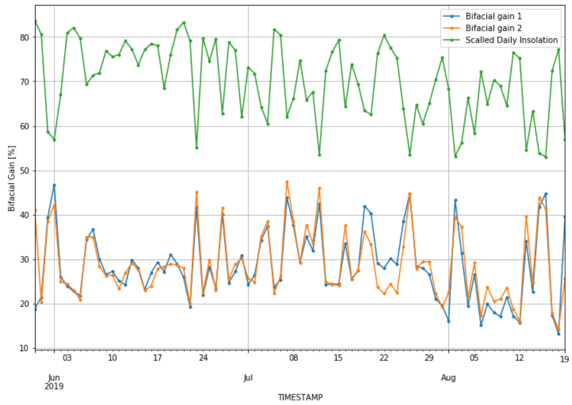


**Fig. 6:** Daily bifacial gains for the South facing latitude tilt system in Fairbanks Alaska.

## 5 SELF-CONSUMPTION CALCULATIONS

In order to calculate a realistic self- consumption rate, it was necessary to normalize the power of the bifacial test system and the comparison system. Nameplate values of the modules were used for normalization of the reference system since this was the only information available. For the bifacial EWV system in Turku, the actual Flash test values were used.

After normalization, the generated PV energy was compared with the residential consumption profiles in each hour of the year. This approach yielded a monthly self-consumption profile, and yearly self-consumption rates were also be calculated. Results are presented in tables II and III as well as in figures 7 and 8.

The nominal power of the residential system was scaled to 3 kWp and 6 kWp as these are fairly typical PV generator sizes in residential houses in Finland. The bifacial system was scaled accordingly.

**Table II:** Self-consumption comparison of the scaled 3 kW EWV Bifi system and monofacial South system.

*3 kW system self consumption rates*

| | Profile 1 | | Profile 2 | | Avr of 8 | |
|---|---|---|---|---|---|---|
| | MoF 1 | Bifi 1 | MoF 2 | Bifi 2 | MoF A | Bifi A |
| Jan | 1.00 | 1.00 | 0.99 | 1.00 | 1.00 | 1.00 |
| Feb | 0.75 | 0.86 | 0.77 | 0.86 | 1.00 | 1.00 |
| Mar | 0.61 | 0.71 | 0.70 | 0.80 | 0.92 | 0.98 |
| Apr | 0.60 | 0.66 | 0.75 | 0.80 | 0.90 | 0.96 |
| May | 0.44 | 0.42 | 0.58 | 0.65 | 0.70 | 0.81 |
| Jun | 0.51 | 0.52 | 0.59 | 0.66 | 0.74 | 0.80 |
| Jul | 0.60 | 0.63 | 0.61 | 0.66 | 0.72 | 0.75 |
| Aug | 0.68 | 0.80 | 0.55 | 0.65 | 0.62 | 0.73 |
| Sep | 0.89 | 0.94 | 0.66 | 0.79 | 0.78 | 0.89 |
| Oct | 0.95 | 0.98 | 0.84 | 0.91 | 0.89 | 0.96 |
| Now | 1.00 | 1.00 | 0.87 | 0.99 | 0.96 | 1.00 |
| Dec | 1.00 | 1.00 | 0.90 | 1.00 | 1.00 | 1.00 |
| Year | 0.62 | 0.66 | 0.65 | 0.72 | 0.78 | 0.84 |
| Gain | | 4 % | | 7 % | | 6 % |

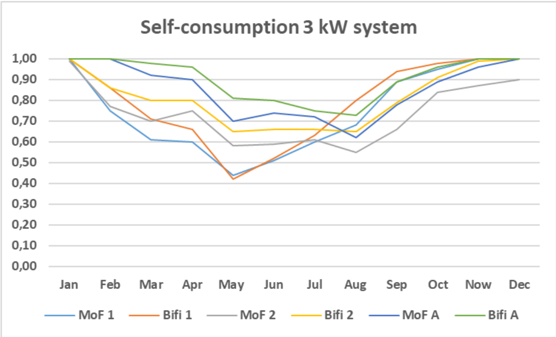


**Fig. 7:** Monthly self-consumption plot of the scaled 3 kW system in Turku.

**Table III:** Self-consumption comparison of the 6 kW EWV Bifi system and monofacial South system in Turku.

*6 kW system self consumption rates*

| | *Profile 1* | | *Profile 2* | | *Avr of 8* | |
|---|---|---|---|---|---|---|
| | *MoF 1* | *Bifi 1* | *MoF 2* | *Bifi 2* | *MoF A* | *Bifi A* |
| *Jan* | 0.90 | 0.99 | 0.90 | 0.99 | 1.00 | 1.00 |
| *Feb* | 0.51 | 0.64 | 0.55 | 0.69 | 0.76 | 0.89 |
| *Mar* | 0.39 | 0.46 | 0.49 | 0.60 | 0.63 | 0.74 |
| *Apr* | 0.38 | 0.41 | 0.56 | 0.61 | 0.64 | 0.71 |
| *May* | 0.24 | 0.25 | 0.41 | 0.44 | 0.42 | 0.48 |
| *Jun* | 0.31 | 0.31 | 0.45 | 0.47 | 0.47 | 0.51 |
| *Jul* | 0.39 | 0.39 | 0.46 | 0.47 | 0.45 | 0.47 |
| *Aug* | 0.45 | 0.53 | 0.41 | 0.45 | 0.38 | 0.44 |
| *Sep* | 0.63 | 0.74 | 0.48 | 0.58 | 0.52 | 0.62 |
| *Oct* | 0.76 | 0.88 | 0.66 | 0.78 | 0.64 | 0.84 |
| *Now* | 0.97 | 1.00 | 0.65 | 0.91 | 0.82 | 0.98 |
| *Dec* | 0.91 | 1.00 | 0.79 | 0.99 | 0.96 | 1.00 |
| *Year* | 0.42 | 0.44 | 0.48 | 0.53 | 0.52 | 0.58 |
| *Gain* | | 2 % | | 5 % | | 6 % |

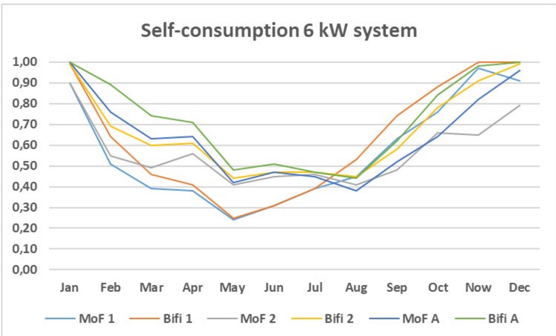


**Fig. 8:** Monthly self-consumption plot of the 6 kW system.

## 6 SUMMARY AND CONCLUSIONS

First calculations show increase for self-consumption rate for the bifacial system. Improvement is affected by the selected reference residential consumption profile, but all showed some gain for EWV Bifi compared to latitude tilt monofacial South system. Averaged residential consumption profile from 8 residences showed 6 % gain in both system sizes, 3 kW and 6 kW. However, more data and calculations are still needed for final conclusions. Data collection from both the sites, Turku Finland and Fairbanks, Alaska will continue.

## 7 ACKNOWLEDGMENTS

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