



Green PE

WP3: ADVANCED POWER ELECTRONICS FOR SMART HOUSES TECHNICAL REPORT

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1. Introduction

An important goal of the Green Power Electronics (Green PE) project was to demonstrate the potential, feasibility and relevance of advanced power electronics (PE) based solutions in the application fields of renewable energies, e-mobility and smart houses.

This document discusses the pilot activities within the application field of smart houses which consist of two pilot demonstrators:

- Pilot demonstrator C1: Demonstration house in Växjö, Sweden
- Pilot demonstrator C2: Benchmarking Si and WBG based solutions at a solar cell system on the roof of Physicum in Tartu, Estonia

The aim of this technical report is to present the activities being done to demonstrate new concepts and solutions for applications of advanced power electronics for smart houses as well as the results. The document includes two main lines of activities: A demonstration of a concept to maximize the use of locally produced energy at a family house in Växjö, Sweden and the activities to develop microinverters in Tallinn, Estonia, that were tested at the solar facilities at Tartu University.

The target group of this output comprises companies in the Baltic Sea Region (BSR) working on energy optimization for housing and industrial plants; companies developing, marketing and selling power electronic systems; building companies and companies marketing and developing solutions for smart housing; companies working on solutions and services for infrastructure such as power production and power delivery, construction sector, public actors and industry associations; business support organizations and international cluster associations.

It is expected that the results presented in this report will increase the competence of the target companies about power electronic solutions and open up possibilities for them to include new products and services in their portfolio thus increasing their international competitiveness. Decision makers and innovators at the relevant BSR companies will gain competence to involve advanced PE in their technology management and R&I strategies. Further information on the relevance for the market of the learnings from this pilot demonstrator is provided in the O3.5 Pilot evaluation and Case studies.

2. Pilot demonstrator C1: Family house in Växjö (Sweden)

Locally-produced solar electricity is one of the solutions to create and use uncarbonated energy. The objective of this pilot demonstrator is to show a concept to maximize the use of locally produced energy.

In this pilot demonstrator, a family house was equipped with a DC-grid and energy storage capability. The activities carried out show that

- it is advantageous to avoid converting electricity back and forth between AC and DC
- lighting and many other house appliances can consume DC directly
- energy can be stored locally in batteries, allowing:
 - Delayed consumption of locally-produced energy
 - Island operation reducing vulnerability to power outage.
- the overall concept can be safely implemented in a family home.

With the presented concept, the solar system installed in a family house becomes more efficient, autonomous and consumes the in-house produced energy in the first place, reducing the interactions with the power grid. Less purchased and less sold kWh indicate a higher degree of self-sufficiency and are in line with the project objectives.

Moreover, the system makes the inhabitants less vulnerable and more independent in case of power outages, which increases resilience in society and reduces variations in power and voltage in the local grid. This results in a more stable grid.



Figure 1: Åsaliden. The family house in Växjö, Sweden where the pilot demonstrator was installed.

Source: Sustainable Smart Houses in Småland

2.1. System description

The villa was originally equipped with 20 solar panels with a capacity of about 5000 kWh per year and 14 solar collectors to warm up water. A large household consumes approximately 6,000 kWh per year for household appliances, heating excluded. This corresponds to an average energy need of 500 kWh per month, or an average power production need of $500\text{kWh} / (24 \times 30) = 700\text{ W}$. A small household with two adults and no children consumes approximately half as much: it needs 250kWh per month (or 8.4kWh per day) for an average power production of 350W.

The pilot provided the house with energy storage capability (charging and backup battery solution). The battery storage is designed to allow for a day of power consumption without external supply. The battery may be of lead- or Li-ion-based. For lead batteries, an 18-kWh battery storage should be selected, about half of which can be used regularly to minimize wear and tear of the battery. The house was equipped with three strings of lead acid batteries of 6 kWh each, for a total of 18 kWh. The battery system strings provide up to $3 \times 18\text{Ah} = 54\text{ Ah}$ at a voltage range of 280 – 367 V.

An additional DC appliance network was working together with the existing AC grid. A control system allowed switching the power distribution between AC and DC either manually or automatically.

The battery was connected to both 230 AC and DC 350 V supporting lighting, communication equipment and appliances. Some electrical equipment was operated directly from a battery without conversion to AC. An energy storage management system and software program have been developed and verified.

The system is standalone with full islandic operation capability.

For a detailed description of the system see Appendix 1.

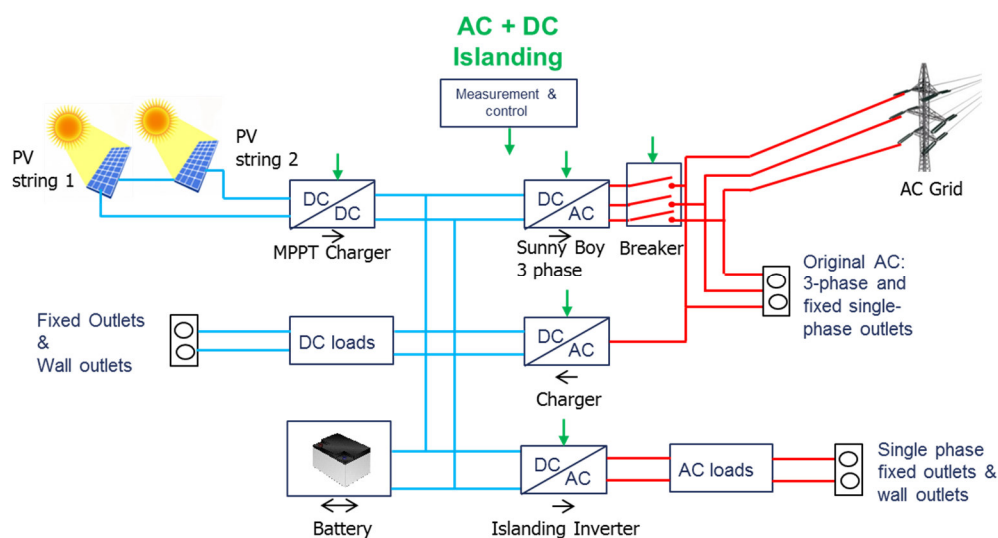


Figure 2: System block diagram. Cliparts from clipground.com, licence CC BY 4.0

Source: Green PE project 2018.

This demonstrator used commercially available Si-based power electronics equipment to demonstrate the concept proposed. Additional improvements expected by using wide band gap (WBG) technology are evaluated in the other pilots and can be integrated for further energy savings.

2.2. Method, design and implementation

At an early stage of the activities, the focus was put into identifying the most relevant issues to demonstrate and to best promote a faster market uptake of power electronic solutions for smart housing. Discussions with industrial stakeholders and decision makers were carried out and an evaluation of the drivers and barriers was done as part of the work with the regional specialization roadmap (see O2.1 “Regional mapping of the sectoral specialisation in some Baltic Sea Regions at some Baltic Sea region countries/regions”)

Buildings with solar energy panels usually sale surplus of energy to the grid. This is, in some countries, not very profitable. Moreover, the energy pumped into the grid at a time when lots of other micro-producers also sale energy to the grid results in supply instabilities. A massive use of solar panels needs the development of a method that will minimize those instabilities. That means that the locally produced energy must be used at the place of production. That can be done by incorporating energy storage capability in the buildings.

During autumn 2016, a master’s degree project was carried out at RISE (at the time Acreo Swedish ICT) and KTH (Appendix 2). The aim of this project was to find the optimal battery size for the already installed PV system at the house in Växjö. Firstly, the existing system was modelled. Then a new model including a battery was built. In this model it was assumed that the aim of the battery is to maximize the self-consumption of the house. A sensitivity analysis was performed in order to study the influence of the battery capacity on the electricity fluxes between the house and the grid. The profitability of the project was also investigated, considering the current tariff schemes for the house and for the “average” Swedish house. All software tools developed during this work are available for design and dimensioning of future systems upon request¹.

The master project demonstrated that the installation of storage capability in a family house was not profitable given the high prices of batteries in the market. The building of storage capability in society is strongly dependent on public subventions.

A stakeholder’s workshop in Kista, Stockholm, on May 29, 2017 gathered representatives from six companies and decision makers to discuss relevant aspects influencing the market uptake of Green PE solutions for smart housing. During this workshop another interesting issue was discussed. In this case, the fact that the storage capability to be implemented had the potential of providing energy in case of power outages. The islandic capability was installed in the house to provide uninterrupted power supply. This is a key element in the demonstration. The islandic capability becomes an interesting factor for decision makers to consider while building up resilience of the society. The use of mini-grids connecting buildings to share locally produced energy showed to be an issue of interest for decision makers that proposed further evaluation of this concept in future activities.

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The energy efficiency of the system can be evaluated comparing the monthly kWh meter registrations for purchased and sold energy to the grid. Less purchased and less sold kWh indicates a higher degree of self-sufficiency and are in line with the project objectives. Since testing and adjustments of the system were performed until autumn 2018 it is not possible to report numbers to evaluate the efficiency of the system in the present report. However, some data collected during the tests indicates the system is increasing the use of locally produced energy in the house and diminishes the transactions with the grid. Further tests are planned after the Green PE project is finalized, during the spring/summer 2019.

A deeper energy efficiency analysis needed the installation of an on-line data acquisition capability more modern than the existing system in the house. This would have been a high-cost project that was not possible to be done within the scope of the Green PE project (budget limitation).

2.3. Achievements and Results

- The project has specified, designed, constructed and completely installed an AC and DC hybrid electrical micro building grid with a storage battery. It is a standalone system with full islanding capacity in full service in a family home.
- The system uses battery connected supply for both 230 AC and DC 350 V in feeding lighting, communications equipment and appliances.
- The project has demonstrated how to construct a hybrid ac and dc island and micro building grid and a family home electrical installation based on standard electrical equipment and components, including energy storage, for a family living there, complying fully with today's existing electrical installation rules.
- The project has demonstrated how to operate lighting and other electrical equipment directly from a battery without conversion to ac.
- There is a high potential in developing installation methodology for this type of installations work to reduce cost. The cost for the electrical installation work was very high because it was a pilot project work.
- The project has developed and verified an energy storage management system and software program in a product.
- The energy efficiency can be evaluated comparing the former energy system monthly kWh meter registration's for purchased and sold kWh by the grid company for one year. Less purchased and less sold kWh indicates a higher degree of self-sufficiency and are in line with the project objectives. A deeper analysis is a high cost project and was not included in the project plan.

2.4. Conclusions

The pilot demonstrated that the installation of DC/AC grid and islandic capability has enabled a higher energy efficiency. This is a novel concept that is being considered as very promising to minimize the drain of energy produced by solar panels. The installation of this system includes the use of intelligent control systems and power electronic-based solutions. The main results of the pilot demonstrator are the following:

- For an increased use of locally produced energy, like in a house with solar capacity, it is advantageous to avoid converting electricity back and forth between AC and DC.

- The solar panels produce DC current and lighting and many appliances can directly consume DC, thus avoiding conversion. The demonstrator proved that lighting, all computers and communication system in the house, pumps in the ventilation channels and others, refrigerators and freezers can function with DC provided a suitable voltage is available for it.
- Energy can be stored locally in batteries, allowing delayed consumption of locally-produced energy and island operation, reducing vulnerability in case of power outage.

These solutions were safely implemented in the family home.

2.5. Future activities

The islandic capability is very appropriate and useful for reducing vulnerability in case of power outage. The concept has shown good potential to increase the preparedness of cities or neighbourhoods for cases of power outage. Decision makers have shown interest in further development of the concept encouraging the pilot team to perform further demonstrations, connecting a number of similar hybrid ac-dc-villas into a DC micro-grid to evaluate the feasibility of the concept for larger-scale applications.

The experience acquired during the pilot activities has shown that there is potential for further development of the installation methodology of the AC and DC hybrid systems to reduce costs.

3. Pilot demonstrator C2: Benchmarking Si and WBG based solutions at a solar energy test station in Tartu (Estonia)

Solar electricity is one example of renewable energetics which helps to reduce the carbon dioxide emission. This reduction is especially important for Estonia, as the country has the largest CO₂ footprint in OECD-countries.

The aim of this pilot is to offer a test-ground to enable a comparison of different DC/AC inverters (applying advanced PE) connected to the photovoltaic (PV) panels, to demonstrate a concept including the analysis of costs & benefits of locally produced renewable solar energy.

Based on the carried-out activities this pilot demonstrator shows that

- It is advantageous to use solar energy also in the Nordic countries, where during the wintertime there is not much sunlight available, but in contrast, summertime will produce a lot of solar energy.
- The summertime produced solar energy is important to cover increasing cooling costs in modern buildings.
- The new generation WBG-materials based inverters produce comparable results to traditional inverters. For improved performance they need a year or two additional product development.

3.1. System description

The pilot demonstrator provided the Physicum (building of the Institute of Physics, University of Tartu) with five solar energy test systems (see Figure 3). The PV capacity of each of them is 3240W. Panel directions SW and NE.



Figure 3: Five PV-test systems on the roof of the Physicum.

Source: University of Tartu and Green PE Project

Three systems are equipped with traditional Si-based inverters (Figure 4). Two others are available for inverter / microinverter (Figure 5) comparison tests.



Figure 4: Three traditional Si-based inverters in Physicum's test station.

Source: University of Tartu and Green PE Project



Figure 5: New generation microinverters based on WBG from Ubik Solutions OÜ at the Physicum's test station.

Source: Green PE project

The electrical connection of PV-panels, inverters, microinverters and the Physicum's building is described in Figure 6.

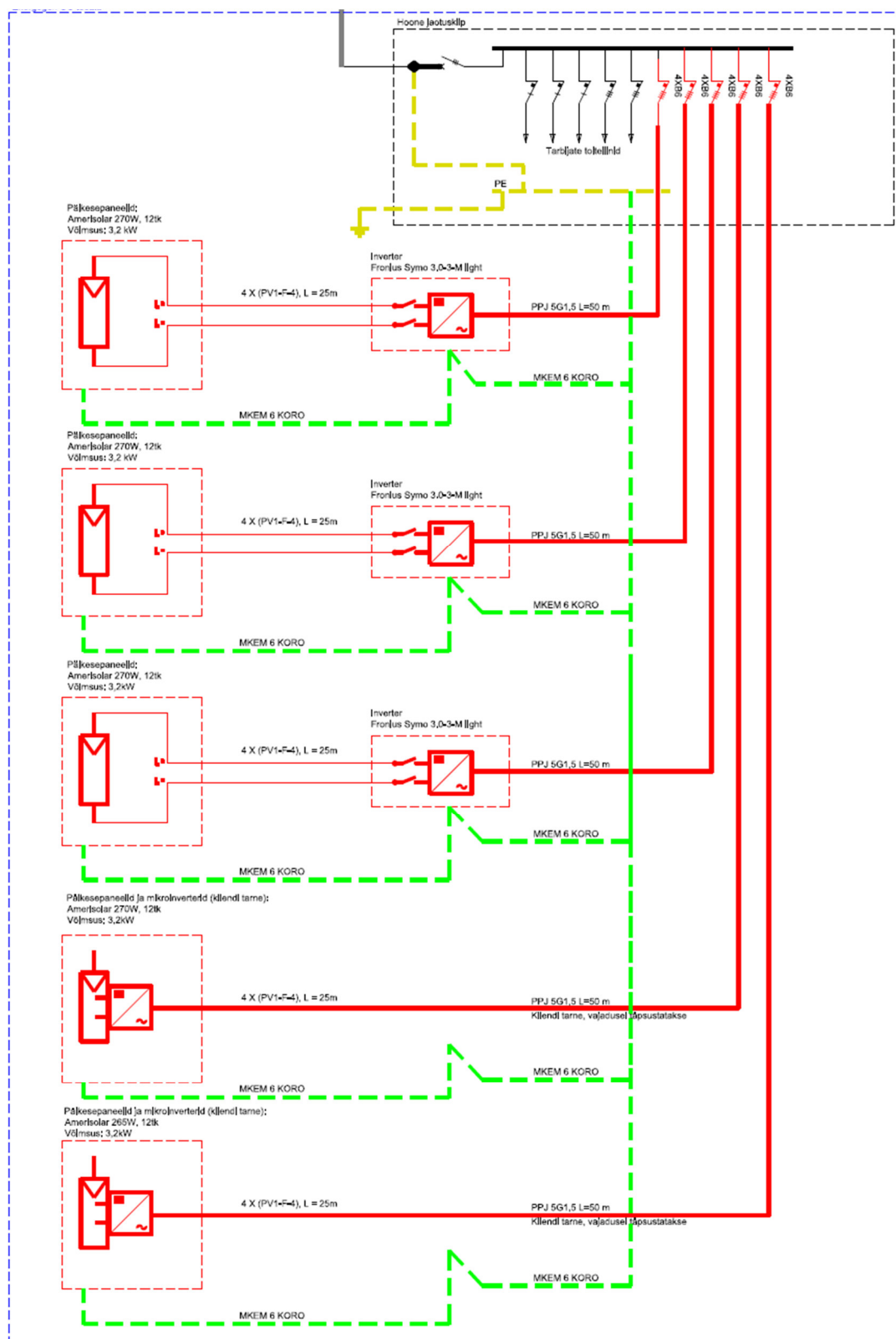


Figure 6: Electrical connection of PV panels and inverters.
Source: *Energogen OÜ prepared for University of Tartu.*

The pilot provided also the uncertainty certified measurement systems and storage capacity for time-series of PV-produced energy values. The Physicum's test ground already had a weather station, measuring among other parameters the temperature, irradiation flux and precipitation. The amount of snowfall is also possible to estimate from collected data. The measured data are stored in a local server and date back to the year 1999.

3.2. Method, design and implementation

The state procurement for building the five PV stations was carried out in spring 2017. Three companies participated. The winner, Energogen AS, built the systems in June 2017. From that time on, University of Tartu has a continuous production of solar energy at the Physicum building.

At the first stage of the installation, the PV panels in each system were oriented partly (6 panels) to SW and partly (6 panels) to NE. Three systems, all of them equipped with traditional Si-based inverters, were working at that time.

During the first month, the total production of PV energy was measured by checking the total production rates from the inverters display, once per day, manually.

From July 2017, the inverters were equipped with local storage capacity and the continuous measurement of solar energy production, with 5 minutes interval, started.

In September 2017 an uncertainty certified measurement system was bought and installed, independent from PV-panels and inverters manufacturer. The uncertainty certified measurement of time series started.

In October 2017, the PV systems were rearranged so that one system was equipped with 12 NE-directed panels, second with 12 SW-directed panels, and third remained as before - 6 panels oriented to SW and 6 panels to NE. An example of these data is presented on Figure 7.

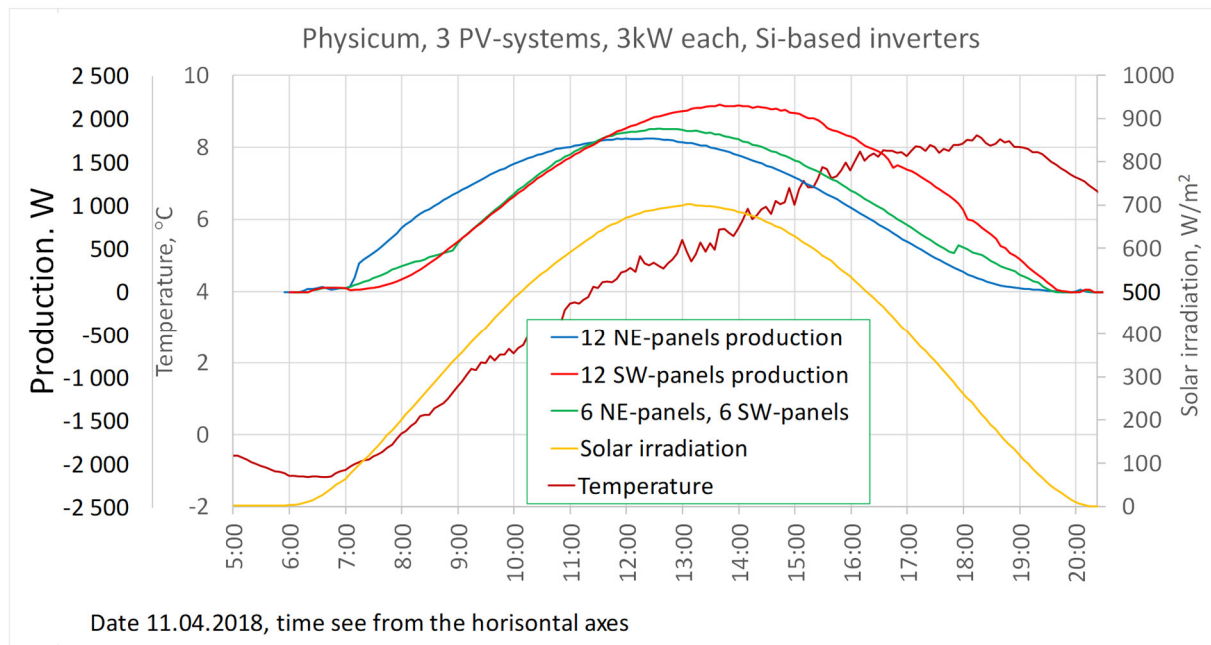


Figure 7: Example of efficiency measurement results in the case of traditional Si-based inverters.

Source: Green PE project 2018.

In September 2017, the first generation of microinverters based on WBG material from the project partner Ubik was installed in the test site. The microinverters were removed for further improvement and were re-installed back after amendment. Finally, from July 2018 on the most recent version of Ubik's microinverter are under test conditions. An example of efficiency data is presented in Figure 8. The improvement process of the microinverters is described in Appendix 2. During the test period and related improvements in Ubik's laboratories, the efficiency of Optiverterers increased by about 40 %. Further information on the microinverters are provided in Appendix 3 and Appendix 4.

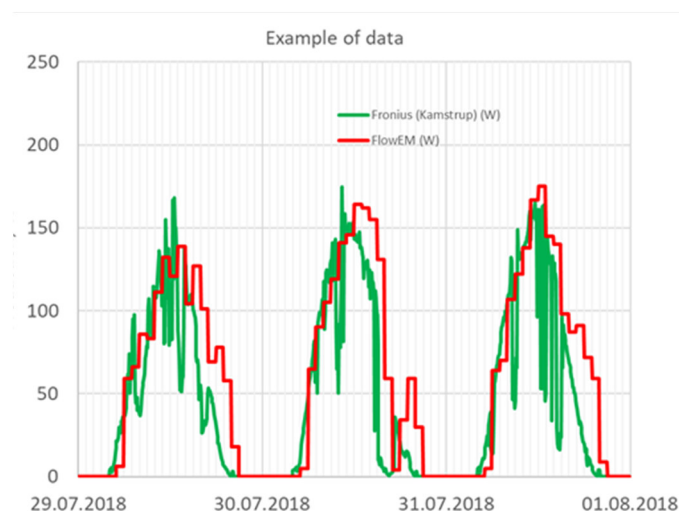


Figure 8: Example of efficiency measurement results (in Watts) from FlowEM software compared to traditional Si-based inverters results.

Source: University of Tartu (Kamstrup measurement results); Ubik Solutions OÜ (FlowEM measurement results)

The new generation inverter prototype from Christian-Albrechts University in Kiel (CAU, Germany) described in O3.2 was intended to be tested at the PV station in Tartu. This prototype showed a 97% efficiency in DC/AC conversion of energy in laboratory tests. The test at the PV station in Tartu was not possible to be carried out before the project finalisation due to technical complications. The intention of the partners is to perform the test in Tartu at a later stage, with partner's own funds.

3.3. Conclusions

The main results of the pilot demonstrator C2 are the following:

- It is possible to use solar energy also in Nordic countries. During summertime, there was a lot of solar energy available (see Figure 11), but in contrast, during the wintertime there is not much sunlight available. The summertime produced solar energy is important to cover increasing cooling costs in modern buildings.
- During the Green PE project lifetime, the Physicums PV-panels produced approximately 11 MWh of carbon free energy.
- The new generation WBG-materials based inverters produce comparable results to traditional inverters. For better performance they need a year or two additional product development.

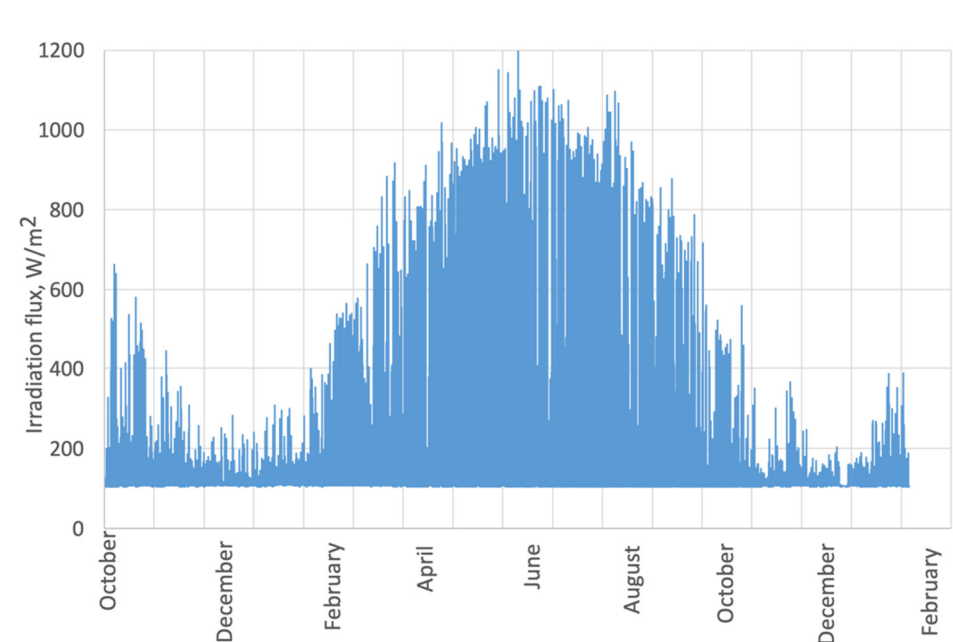


Figure 11: Irradiation flux during the PV-measurements period. Physicums weather station.

Source: University of Tartu

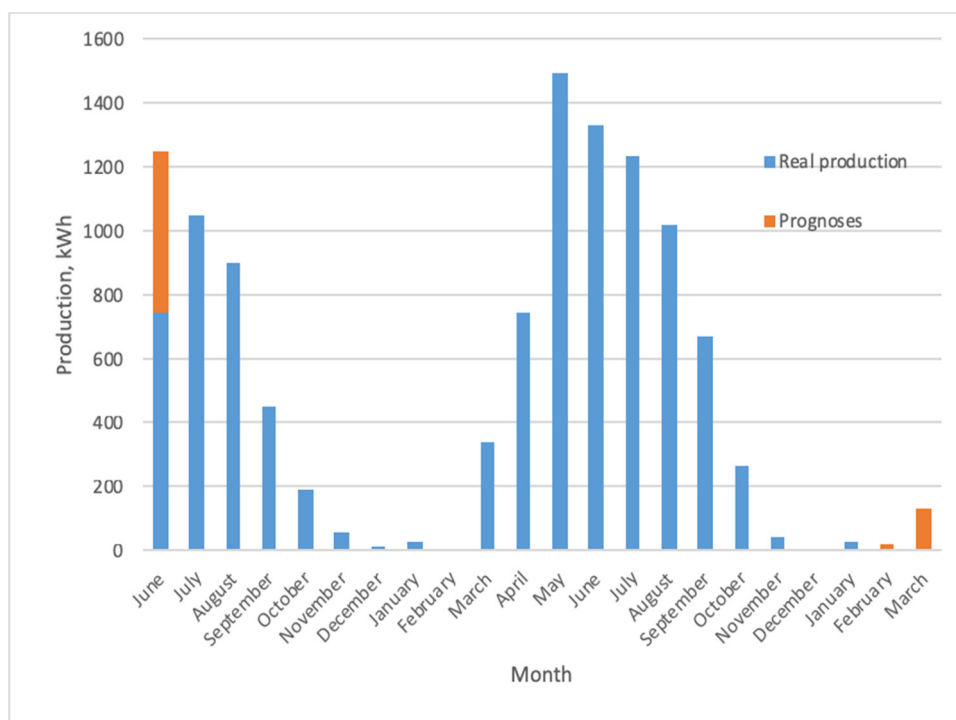


Figure 12: Total energy produced by the Physicum's PV systems.
Source: Green PE project 2017-18

3.4. Future activities

In this pilot demonstrator the efficiency of new generation inverters based on WBG material compared to traditional ones were tested. These tests must be continued for longer time, to be able to make also conclusions about the reliability of the tested products.

Another follow up activity is to buy and test new generation WBG-inverters for a reference also from the market. During the project duration it was not yet possible. When the real commercial products will be available, further new efficiency comparisons and reliability tests could be carried out.

APPENDIX 1

John Åkerlund, 'Electrical power system with storage for villas. AC 230V/DV 350V. Technical specifications. UPN 2018.

APPENDIX 2

Maria Letizia Fasci, 'Feasibility study of an energy storage for an energy-efficient house', Marter's Degree Project. Stockholm, Sweden, December 2016.

APPENDIX 3

Dmitri Vinnikov, Andrii Chub, Elizaveta Liivik, Roman Kosenko and Oleksandr Korkh. 'Solar Optiverter. A novel hybrid approach to the photovoltaic module level power electronics'. IEEE Transactions on industrial electronics, Vol. 66, No. 5, May 2019.

APPENDIX 4

Andrii Chub, Oleksandr Korkh, Roman Kosenko, Dmitri Vinnikov, 'Novel Approach Immune to Partial Shading for Photovoltaic Energy Harvesting from Building Integrated PV (BIPV) Solar Roofs'. EPE'18 ECCE Europe ISBN: 978 - 9 - 0758 - 1528 - 3 - IEEE catalogue number: CFP18850-ART

Project Facts

- 17 project partners: research institutions, companies and technology transfer organisations
- Duration from 2016 to 2019
- Budget: EUR 3.1 million
- European Regional Development Fund
- Interreg Baltic Sea Region Programme
- Led by University of Southern Denmark

Project Partners

- University of Southern Denmark (Denmark)
- Applied Research Institute for Prospective Technologies (Lithuania)
- Christian Albrechts Universität Kiel (Germany)
- CLEAN (Denmark)
- Converdan A/S (Denmark)
- Kaunas Science and Technology Park (Lithuania)
- Kaunas University of Technology (Lithuania)
- Latvian Technological Center (Latvia)
- NATEK Power Systems AB (Sweden)
- Polish Chamber of Commerce for Electronics and Telecommunications (Poland)
- Renewable Energy Hamburg (Germany)
- RISE Research Institutes of Sweden AB (Sweden)
- Sustainable Smart Houses in Småland (Sweden)
- Ubik Solutions OÜ (Estonia)
- University of Latvia (Latvia)
- University of Tartu (Estonia)
- Warsaw University of Technology (Poland)