Executive Publishable Summary

PV-MIPS
Photovoltaic Module with Integrated Power Conversion and Interconnection System

Project website: http://www.pvmips.org

Coordinator:
Institut für Solare Energieversorgungstechnik, ISET e.V.
Königstor 59
D-34119 Kassel, Germany
T: +49 561 7294 244
F: +49 561 7294 400
email: info@pvmips.org

Abstract

A solar system achieves the highest output when every solar module is continuously operated at its maximum power point. This can be reached by using module-integrated inverters. In this case, every solar module has its own controller. Module-integrated inverters lead to higher yields especially with solar modules that are partially shaded or aligned with different angles. Other advantages are that the design of the PV system is more flexible and that it can easily be expanded; in addition, costs for DC wiring do not apply. However, as module-integrated inverters are still quite expensive compared to their bigger counterparts, a breakthrough in this wiring concept has not yet been achieved.

However, by the use of modern integrated power semiconductors and new approaches in photovoltaic module technologies the cost-performance ratio can be improved. The aim of the project is to develop a low cost module technology with an integrated inverter that can feed solar electricity directly into the European grid.

Within the scope of the project, ISET and eleven partners from Germany, Austria, Greece and the Netherlands want to reduce the total costs of a PV system to 3 Euro per watt by the end of 2009. Besides ISET, the following research institutes and companies are involved:

- Österreichisches Forschungs- und Prüfzentrum Arsenal GesmbH,
- Stichting Energieonderzoek Centrum Nederland,
- Philips Lighting Electronics,
- Würth Solar GmbH & Co. KG,
- Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg,
- European Power Semiconductors GmbH (now Infineon AG),
- Netherlands Organisation for Applied Scientific Research,
- Heliodomi S.A.,
- MVV Energie AG,
- Lafarge Roofing Benelux and
- Ecofys energy and environment.

Inverter costs will be reduced to 0.3 Euro per watt. Here, the potential to save costs and components is especially high, as standard cases and heat sinks can be omitted due to the module integration. Furthermore, by using a high voltage solar module the transformer inside the module can be waived. This reduces the costs as well as the losses. In order to yield a high module voltage the main attention is directed toward thin film technologies where a structuring

of the module in small elementary cells is easily possible. The series connection of these cells inside the module provides voltages of several hundreds of volt.

A three phase grid connection of the inverter provides a continuous power flow from the PV-module. Thus the size of storing components at the DC port can be reduced drastically.

Altogether, the direct coupling without transformer and the three phase approach will lead to an inverter that is remarkably smaller, less expensive and more reliable.

Besides this entirely new approach with high-voltage PV modules and three phase grid connection a second approach is applied using standard low-voltage modules. In particular for crystalline silicon based PV modules, now the dominant technology, a high-voltage module is not easy to produce. Nowadays modules provide a voltage level of several ten volt. However even in this case a technical edge can be achieved by means of integrated electronic devices, high switching frequencies and new magnetic materials.

To reach this challenging objective, an integrated approach is applied: PV-MIPS combines the knowledge of semiconductor experts, manufacturers of solar modules and power electronics. A separate work package deals with the regulations and standards to ensure that any utility requirements are met and that the modules with integrated inverters can be installed in all countries of the European Union. One focus of the project is building-integrated PV, because the potential for these applications is especially high in the dense populated areas of Europe.

During the present reporting period the following work packages were active.

Detailed summary of each work package

WP 1: Technological and economical requirements of the market and evaluation of concepts.

As a start of the project first the market potential of the module integrated inverter concept and the subsequent technical and economical requirements were determined.

An inventory on module integrated inverter concepts that are and were on the market learned that reliability is the key issue. In general for an inverter, the time between failures, is considerably shorter than the module lifetime. For an inverter that is attached to a module it is even more difficult to achieve a lifetime comparable to that of a module, as outdoor conditions are significantly more severe than indoor. In particular high temperature, humidity and temperature changes affect the inverter lifetime. Replacing a defective inverter, if possible at all, is very expensive in cause of a sloped roof mounted system leading to a reduced system performance.

A second point of attention is the inverter costs. Though, balanced by a higher system output, for an inverter manufacturer it will not be easy to sell a small inverter at a higher cost than a large inverter. Therefore, new electronic designs based on high integration, a low number of components and mass production should be the way to go!

In the Netherlands AC modules turned out to be the main driver in the sales of small rooftop PV systems.

On the basis of the inventory of AC-module experiences the PV-MIPS concept and the requirements were defined:

- Inverter lifetime > 20 years
- Inverter price < 0.3 €/W
- 200 watt module inverter

The unique selling propositions of the PV-MIPS concept are:

- Ease of installation
- No DC cabling

- Higher output in case of shading
- Flexibility in system size

The market segments that can be addressed successfully are:

- Building related systems of any size: simplicity of installation
- Larger systems where shading occurs
- Emerging markets (as little expertise is required to install the system)

In case of a price-competitive inverter per watt all market segments can be addressed. Any PV systems to be planned can benefit from the PV-MIPS concept due to the simplicity of installation, the high system performance and the flexibility.

The most important present and emerging markets in the EU were analysed. With the present support mechanisms large systems are favoured, despite the fact that the intrinsic value of building related PV systems is higher. This can be a disadvantage for the introduction of module-integrated inverters as their advantage is most prominent in building related PV systems.

For the long term it is believed that the inherent advantage of building related PV – electricity generation at the point of use where the value is highest and efficient land use – will prevail.

To support the development of building related PV-MIPS concepts in WP6 a table is made with the advantages of the modular concept related to the market segment and/or actor in the market.

An analysis of the cost break-down of a PV system learns that 60 to 70% of the investment costs goes to the module and only 10% to the inverter. Therefore, the focus should be on system performance and reliability and less on cost. Reality is however, that it is difficult for a non-expert consumer to assess system performance and so selling a system is usually based on initial investment.

Inverter prices are expected to be around 0.3 €/W in 2010[1]. A preliminary cost analysis of Philips learns that after product and manufacturing optimisation a price off factory of 0.25 €/W is feasible. To have reasonable cost margins either the market must recognize the benefits of the modular PV-MIPS concept or new innovative electronic designs must be used.

WP 2: Miniature small power inverter

Within this work package the inverter concept for small power solar inverter has to be defined. The main criteria are lowest system cost, high reliability and life-time. It has to be optimised for module integration, integrated module interconnection and mounting. The inverter should be suitable for integration in PV modules from different manufacturers. A functional model of the inverter for one type of PV module should show the feasibility of the concept. Additionally, an interconnection device should be prepared to increase installation efficiency and reliability of the overall system. In order to further reduce costs an efficient manufacturing process has to be set up. In contrast to WP 3 this development applies to low-voltage crystalline PV module which represent the main share of the market today.

The work package leader Philips sold its inverter business meanwhile. These tasks are vacant but the consortium has promising contact to new partners from industry.

[1] EPIA Roadmap
PV-Trac A vision for photovoltaic technology for 2030 and beyond

WP 3: Integrable small size transformerless inverter

The activities in WP3 can be grouped in three categories:

- Investigation of power modules for solar inverters
- Inverter development suitable for high-voltage modules
- Investigation of relevant codes and standards

Regarding integrated power modules different aspects have to be considered to fulfil the requirements of solar applications. One main item in this period was the technical feasibility study of a 1200V IGBT module. These very small modules were normally used as 600V module. To fulfil all requirements on the higher voltage level, technical improvements on the isolation behaviour have to be introduced and changes in the mounting of the IGBT-module have to be made.

A second aspect was the change in the principal material for the isolation. Different materials have been investigated. In combination together with different application techniques a matrix of material and technical process has been developed and evaluated. The results are shown in the second part of this report.

The inverter development started with an investigation of circuit topologies and control schemes. Only three phase approaches were respected in order to minimize the energy storage components on the DC side. Furthermore the use of transformers (both 50Hz as well as high-frequency types) should be avoided. It turned out that this direct coupled approach has some drawbacks since the high module voltage which is necessary for one stage voltage DC-link inverters is inconsistent with the maximal blocking voltage of semiconductor switches. Thus the focus was on current DC-link inverters. In this case the feed-in can be managed with a lower voltage on the DC side.

Two different control schemes were taken into consideration: on the one hand a pulse-width modulation (PWM) of the power switches and on the other hand a pulsing with the fundamental 50 Hz frequency. The circuits can be realised with MOSFETs or IGBTs respectively.

Currently simulation results of these topologies are available. Furthermore a test circuit with power MOSFETs was realised in order to specify some properties like losses and thermal behaviour.

Relevant standards regarding grid connection and electromagnetic compatibility have been used in order to specify the properties of the AC port of the inverter.

WP 4: Design of high voltage modules for inverter integration

The work performed in the first project phase within WP4 can be separated into three parts. Initially, we had to find out how the high voltages needed for the integrated power converter could be best achieved. This included calculations to determine the influence of various parameters of CIS solar cells on the performance of the module. Apart from several known CIS properties, we needed further data which is not relevant for standard CIS modules and was therefore not available in a suitable form. Therefore, the second focus of the work was the question whether and how, by increasing the cell voltage by means of varying the Ga content in the absorber of the CIS cells, the performance of high voltage modules might be improved. Thirdly, we focussed on finding adequate processes in order to reliably isolate neighbouring module sections which show great differences in voltage, while ensuring low area losses and a reliable isolation even in the encapsulated modules for their expected life-time.

WP 5: Manufacturing of high voltage modules for inverter integration

As a base for the high voltage modules, a laser ablation system was designed and developed. A special laser was developed for ablation. The system was delivered in may 2005 and set up. Before starting with the production of the first module generation some tests and development with the system were made.

Tests were made concerning the surface and the isolation resistance over the ablated area. Isolation tests at 600 V DC were performed with good results. The optical behaviour also had to be optimised in terms of full transparency. A closer investigation will be the ablation of the photoactive layer without getting short circuits at the edge caused by melting.

Nevertheless an important point was the process time. After calibration and optimisation the process time reached a minimum and was much shorter than the time a mechanical treatment would need. The production of first module prototypes (varying voltage range, size) were done. In order to optimise the manufacturing processes the impact of the laser ablation on consecutively processes were checked. Here special effort has to be put in the lamination process.

Although the optimisation of laser ablation were delayed due to severe problems with the laser stability more than 800 tests were successfully performed.

Achieved results so far are:

- Design optimisation with respect to manufacturability
- Manufacturing and testing of first prototypes
- Tests with the laser ablation system
- Isolation tests with the decoated area
- Roughly good isolation after 2 subsequent laser treatments

Within the next periods the following results are expected:

- improved isolation properties
- further reduction of laser process time compared to mechanical treatment.

WP 6: Integration of electrical interconnection and mechanical interface

With Ecofys, Philips and Lafarge it was discussed what the needs are of the building sector and how advantage could be taken of the unique modular properties of the PV-MIPS concepts.

To have successful application of PV in the building sector, a PV system must become a building product. PV should be a building product, fitting in the building process.
Important factors are:

- maintenance on a roof is usually expensive and should be avoided
- the electrical layout of the system must be simple leading to little planning time and installation that does not require too much additional expertise
- it should fit in the building process: logistics + roofers must be able to do the installation
- it must fulfil the normal building requirements (water tightness, wind, fire, ..)

As installers usually have their profit in selling their own mounting system and to improve acceptance it was decided to focus on an easy electrical system and apply the existing mounting systems for the time being. PV-MIPS allows for an easy daisy-chain cabling with fixed cable lengths as it is based on a high-voltage bus system. Either conventional electrical connectors can be used or a new innovative punch cable system.

WP 8: Investigation of the impact of PV-MIPS on the power quality and safety of LV grids

The overall objectives of WP8, “Investigations of the impact of PV-MIPS on the power quality and safety of LV grids” during the first 18 months of the project are

- Research and deep review about currently existing standards in EU countries and important markets outside Europe.
- Comparison of the conditions and set of problems for network connection in different EU countries.
- Exchanging information about required protection systems, power quality levels the devices have to comply with and test procedures between the project partners.
- Identify gaps in existing standards and reveal items where the current regulations are not appropriate for MIPS

During the first reporting period research activities were concentrated on the following tasks:

- Identification of a set of key topics, which are of interest for the interconnection of PV-MIPS with the networks and taking into account the experiences and needs for the specification, design and development of PV-MIPS.
- Preparation of a common topic based questionnaire for the survey of the current framework and requirements for the grid interconnection of PV-MIPS.
- Topic based analysis of relevant documents which define the technical conditions for the grid interconnection of PV-MIPS in selected European countries as well as important markets outside Europe. This survey covered the following countries: Austria, Spain, It-aly, France, Germany, the UK, The Netherlands, Belgium, Poland, the U.S.A. and Japan.
- Drafting of a common structure based on the results from the questionnaire survey and the collected documents. This structure will provide the framework for the extraction of the relevant information out of the listed documents and the final documentation of the set of requirements in different countries.
- Development of a “requirements comparison matrix” which allows adequate means to compare the different requirements in the considered countries.

The main result gained from the work during the first period consists of a comprehensive overview of the documents which currently define the technical framework for grid interconnection of PV-MIPS in the main markets in as well as outside Europe. Primarily, this information is fundamentally required by the project partners who design and develop the PV-MIPS devices. Furthermore the results will provide the basis for the development of dedicated product standards and guidelines which will be crucially needed for the successful implementation of the PV-MIPS concept.

WP 9: Training

Within this work package the project website was designed. Under www.pvmips.org some information about the project aims and the partners involved can be found. In a password secured area internal project documents can be found. The access is allowed to project partners only.

In order to promote the project publications were submitted to the European PV-Conference in Dresden (September 2006) where a professional audience is addressed.