NEXT GENERATION OF AC-MODULE INVERTERS

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ABSTRACT: In 1992 the development of the OK4 AC-module inverter was started. Currently the OK4 is in production and sales are rapidly growing. It shows that there is a substantial market for micro-inverters, especially for small PV systems of 200-400 Wp. In this paper we first question the future of AC-module inverters in view of market developments and market demands. We will also discuss the application of AC-modules in larger PV systems. The requirements for the next generation of AC-module inverters are based on these developments and demands. Finally we conclude that these requirements can be met, but only when new inverter topologies are being used.
Keywords: AC-modules - 1: Cost reduction –2: Building integration -3

1. INTRODUCTION

The development of the OK4 AC-module inverter was started in 1992. Since 1997, with many improvements and revisions, the OK4-100 is in true series production. It was the first and only small sine-wave inverter in the world [2]. With the OK4-100 it has been proven that is was possible to develop a micro inverter whilst meeting requirements of quality, reliability, lifetime and safety [3, 10]. Large scale production, together with improvements facilitate easier production will reduce inverter costs. It is expected that by the year 2000 more than 50,000 OK4-100's will be installed. The growing sales, proves that there is indeed a substantial market for micro inverters.

The question is would we make the same choices regarding power, size and technology if we could start all over again? Special attention should be made to market developments and market demands.

2. CURRENT STATUS AC-MODULES

First of all we see an expanding market for AC-modules. The main driving force for the growth of sales are the low initial costs, the easy expandability of PV systems based on AC-modules and the need for consumers "to do the right thing" for the environment. Although AC-modules are merely used for small PV systems of up to 400-600 Wp, at the same time we see that large-scale projects have started. A good example is *PV-groei* [PV growth] in the Netherlands [8]. This project aims at installing four AC-modules on 10,000 roofs (Fig. 1).

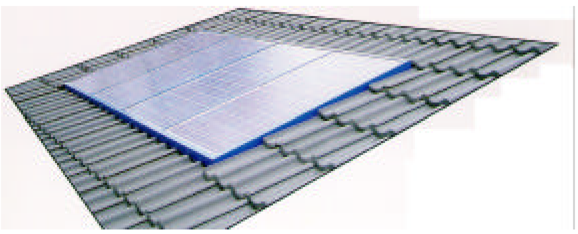

Figure 1: *PV-groei* [PV growth] is an example of a large scale PV project with AC-modules [8].

For this project collaboration has begun between three utilities (Eneco, ENW and REMU), NKF KABEL B.V. and Shell Solar.

Moreover, we see that AC-modules are not only being used with polycrystalline PV modules. Just recently in the Netherlands the first amorphous AC-modules were installed (Fig 2.)

Figure 2: Installation of the first amorphous AC-modules in the Netherlands. [Photograph courtesy of Peter van der Vleuten, Free Energy Europe, The Netherlands]

Based on data of the first larger field projects with AC-modules, we conclude:

? The costs of installation are less because standard AC wiring can be used instead of DC wiring.
? The average output per PV module is higher as the mismatch losses on system level are less.
? The installation of AC-modules is less complicated compared to traditional systems, which decreases the installation costs.

3. MARKET DEVELOPMENTS AND MARKET DEMANDS

In the PV market we distinguish two main developments. First there is a tendency, especially in Europe, to integrate PV in the building environment (Fig. 3). This development asks for easy and safe installation, as well as easy expandability. Moreover, PV modules must be compatible with building integration designs. Special attention should

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be given to safety, as implementation in the built environment implies that PV modules and cabling in practice become accessible to unauthorised persons, such as playing kids, fire men, window cleaners, etc.

Figure 3: Example of integration of PV in the built environment

Secondly, we see a lot of developments in the PV technology. This development has already resulted in an increased size of both PV cells and PV modules. It is expected that this tendency will result in larger PV modules with larger cells (Fig. 4). Moreover new technologies are being introduced, like amorphous cells. Thus, we see a diversification of PV modules in the market in view of power and voltage.

Besides market developments, there are additional demands regarding PV modules, which are closely related to inverter integration. These are safety, reliability and a decrease of costs of PV in general. Regarding the latter aspect, the inverter especially can influence the BOS costs.

4. IS AC-MODULES THE RIGHT SOLUTION FOR THE FUTURE?

The question is whether AC-modules comply with the described market developments and demands. Regarding the implementation in the building integrated environment we conclude that indeed AC-modules are the best solution, especially regarding easy and safe installation, as well as easy expandability. The requirement that PV modules should be compatible with building integration designs implies a requirement for the next generation of AC-module inverters.

Especially regarding safety AC-modules are a strong alternative, as additional safety measures are not required as long as the inverter meets Class II isolation. This has also a strong impact on the costs of PV-modules, as such additional safety measures can be quite expensive. Field experiences and laboratory experiments with AC-modules indicate that indeed AC-modules are as reliable as traditional single inverters. Moreover, most of the AC-module inverters include the possibility to monitor the AC-modules separately, which increases the control over the PV system. Finally, by using AC-modules the BOS costs decrease considerably, especially because standard AC wiring can be used instead of DC wiring. Also the labour costs decrease, as AC-modules are easy to install and do not require special engineering skills.

5. REQUIREMENTS OF THE NEXT GENERATION OF AC-MODULE INVERTERS

Based on market developments and market demands, we have formulated a number of requirements for the next generation of AC-module inverters, which are listed in Table I.

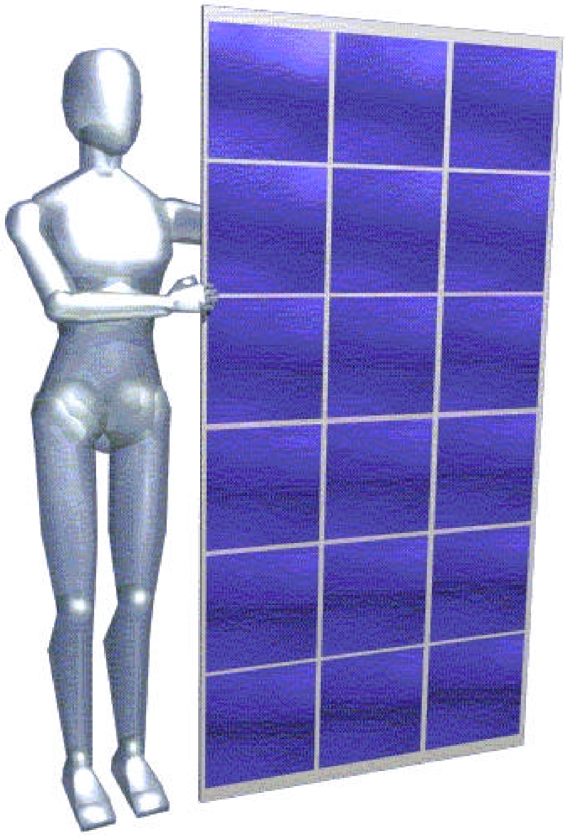

Figure 4: Innovative PV technologies will lead to a new type of PV module

6. PRELIMINARY RESULTS

With these requirements in mind, new innovative concepts have been investigated. Two of these seem to be very promising, and currently we are in the process of obtaining a patent for these topologies. Combining topologies, especially the size of the inductive components can be decreased, which will have a great impact on the costs of the inverter. The size of capacitors and Mosfets will decrease. Finally, the manufacturing costs will decrease, especially at larger series.

When both topologies are used the efficiency of the inverter at full power will be approximately 95%, whereas the size of an inverter of about 300 Watts will become approximately 220 x 70 x 20 mm (l x w x h, Fig. 5).

A major advantage is that most of the analogue control circuits are eliminated and replaced by standard low cost digital logic circuits. These circuits can be integrated into one low cost custom-made control chip (ASIC).

Unfortunately, the new topologies also have their disadvantages. The optimal ferrite shapes and Mosfets are not available on the market yet, whereas the electronics to control the inverter will become more complicated.

Table I: Requirements for the next generation of AC-module inverters

Market development/ Demand	Inverter requirement
Implementation in built environment	✍ Design must be compatible with building integration designs ✍ Optimised electrical and mechanical connection to the PV module ✍ Low profile electronics design ✍ Easy multiple AC connections ✍ Power rating in the order of 200-400 Watts (initial) up to 400-1000 Watts ✍ Suitable for low DC input voltages (< 100 Volts) ✍ MPPT voltage window optimised for future PV technologies
Innovation of PV technology, especially increased size of PV cells and PV modules	✍ Power rating in the order of 200-400 Watts (initial) up to 400-1000 Watts ✍ Suitable for low DC input voltages (< 100 Volts) ✍ MPPT voltage window optimised for future PV technologies
Safety	✍ Class II isolation to avoid special safety measures for PV modules
Reliability	✍ Lifetime of > 20 years to match with lifetime of PV module ✍ Highest possible efficiency (> 95%) to decrease temperature stress and to increase lifetime ✍ High temperature resistance
Decrease of BOS costs	✍ Suitable for very low DC input voltages (< 30 Volts) to eliminate bypass diodes ✍ Lowest possible price per Watt (< US$ .50 per Watt)

7. CONCLUSIONS

In this paper we have shown that AC-modules inverters are an interesting alternative for traditional inverters, not only for small systems, but in the future also for larger systems. Therefore, efforts have been taken to investigate new innovative concepts that might meet future requirements for AC-module inverters. Preliminary results with new topologies show that these requirements can be met.

However, in order to make AC-modules a serious option, more attention should be given to the integration of the AC-module inverter with the PV module itself, especially when we consider implementation in the built environment. It concerns easy installation of the inverter on the PV module, integration with the junction box. Moreover, easy solutions need to be found for the installation to minimise the time involved in installing the AC-module systems.

In order to achieve minimum costs at system level and possibilities for optimal building integration, close co-operation between PV module manufacturers and inverter manufacturers is essential. Therefore, we herewith invite interested manufacturers to contact us. Currently the electrical specifications of the inverter are not set yet, and therefore still can be adapted.

8. ACKNOWLEDGEMENTS

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Figure 5: Impression of next generation of AC-module inverter of 300 Watts.
Actual size: 220 x 70 x 20 mm (l x w x h)