NEW PV SYSTEM CONCEPT – WIRELESS PV MODULE PROTOTYPE

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ABSTRACT: A first wireless PV module prototype is presented. The energy transfer from the solar cells to the string cable is done using the inductive power transfer technology. A half-bridge LLC resonant converter is designed for the DC/AC conversion. The wireless module consists of 60 half-cells and an integrated planar coil. The resonant converter is not yet integrated into the module, but it can be connected externally to the planar coil. The energy is transferred from the primary coil to the secondary planar coil placed outside of the PV module on top of the primary coil. An active rectifier is connected to the secondary coil and it feeds the DC system cable. The first measurements yielded in an efficiency of 88.2 % including the resonant converter, the inductive power transmission and the active rectifier efficiencies. The corresponding output was 207 W.
Keywords: PV system, inductive power transfer, AC modules, resonant converter

1 INTRODUCTION

In 2018, the PV system related costs amounted to 970 $/kWp for commercial applications and system sizes of 200 kWp according to the NREL benchmark report [1]. In that case, the soft costs are disregarded including the land acquisition, sales tax, overhead, net profit, etc. The cost share for the PV modules is 48 % whereby half of that falls to the share of the cell production. The inverter cost amount to 8 %. The cost for structural and electrical balance of system (BOS) are 27 %. The labour costs including the necessary equipment for the installations correspond to 17 % [1].

The levelized cost of electricity depends not exclusively on the initial costs. There are other factors such as lifetime of PV system components as well as maintenance cost due to system component defects. The IEA PVPS task 13 analysed frequently occurring PV module and system defects. In the first year after commissioning, the main defects represent potential induced degradation, connector failures, junction box defects or defective bypass diodes [2].

The proposed new wireless [3, 4] PV system concept affects three quarter of the present PV system in terms of costs with potential cost reductions regarding BOS, installation and maintenance. Additionally, it should eliminate common system component failure.

2 NEW PV SYSTEM CONCEPT

The final goal is to realise a PV system that is based on several serial connected AC PV modules [5]. The DC current of the solar cell matrix is converted into high frequency AC current inside the PV module by a specially designed micro-inverter. Then, the AC current flows through a planar coil generating a magnetic flux. Outside of the PV module, a module clamp covers the primary coil from both sides. This clamp contains a magnetic circuit consisting of ferromagnetic material that transfers the magnetic flux from the primary coil to the secondary coil. The winding of the secondary coil has to be built by the system cable itself. The system cable feeds an AC/AC converter to connect the PV power plant to the electricity grid.

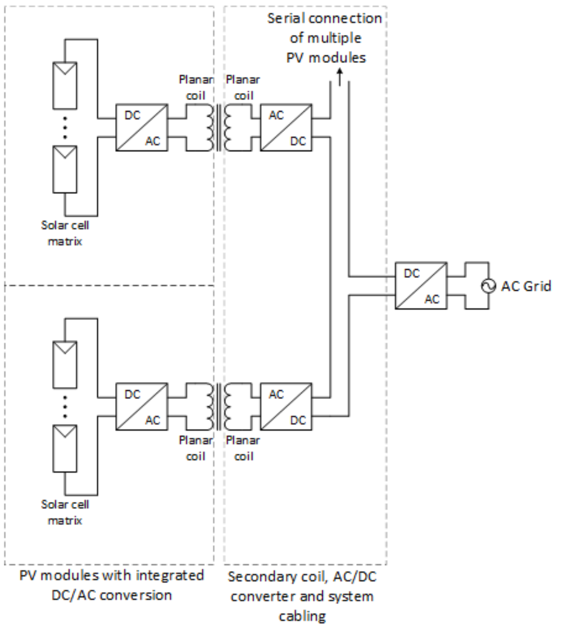

Figure 1: The electronic schematic represents the new PV system concept based on several PV modules with the module integrated inductive power transfer (IPT) that are connected on a DC bus.

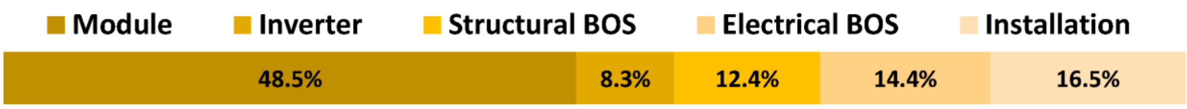

Figure 2: The cost breakdown is shown for a commercial 200 kWp PV system according to the NREL benchmark report in 2018 [1]. The soft costs are disregarded including the land acquisition, sales tax, overhead, net profit, etc.

The engineering complexity of such a system is very high. Therefore, an intermediate system solution is developed where the system cable transports DC current instead of AC. This is done by using another planar coil as secondary coil and by placing it outside the PV module on top of the primary coil. Then, the high frequency AC current from the secondary coil is rectified and fed into the system cable. The rectification is made by an active rectifier, which has fewer losses at low voltage applications. For this intermediate development, an inverter connects the PV power plant to the electricity grid. The two main advantages of the intermediate system solution are that there is no need of the high frequency synchronisation and that the feasibility of wireless PV module can be demonstrated at an earlier stage. The power stage of the micro-inverter within the PV module is the same for the intermediate and final system solution. The transition to the purely AC system can be done by removing the active rectifier and by adding the new control and sensing structure for the synchronisation.

The whole system can be described as a high frequency transformer based grid-connected inverter where the high frequency AC stage is inside the PV module. Figure 1 shows the electrical schematic of the proposed new PV system concept.

This new wireless PV module combined with a clickable mounting system [6] has several advantages such as:

- No electrical connectors
    - Faster installation
    - No weather-related connector failures
    - Less electrical expertise needed
    - No junction box needed
- Galvanic isolation:
    - No PID
    - Higher system voltages allowed
    - Less copper needed
- IPT allows disconnecting under load
    - Reduction in maintenance cost
    - Increased safety of people
    - Increased fire protection (no arcs)
- Individual MPPT tracking
    - Less mismatch losses
    - Less shading losses

This new solution approach for PV systems is designed for applications in large ground-mounted, rooftop or facade PV power plants. The main reason is that a certain amount of AC modules is needed to reach the higher voltage level and that the potential in labour costs reduction and the benefit of industrial prefabrication are greater for large systems.

3 FIRST PROTOTYPE

A solar module with 60 half-cells was manufactured using a backsheet, a triple EVA layer and a 2 mm front glass. The cross connector are led out at the long side of the module. Additionally, a planar coil was placed near the short side of the module and the connection wires are led out the same way. With this setup, external prototypes of a micro-inverter can be connected for testing and engineering purposes of the wireless PV module system. The module is shown in Figure 3.

The DC/AC conversion is made using a half-bridge topology with an LLC resonant circuit shown in Figure 4 where the inductances are built by the leakage and main inductances of the primary and secondary coils. The resonant capacitor is in series configuration on the primary side. This topology does not need additional inductor components and it allows zero voltage switching.

The solar cell matrix is connected to the half-bridge generating a unipolar square-wave voltage. The series resonant circuit is formed by the resonant capacitance Cr, the resonant inductance Lr and the magnetising inductance Lm of the transformer. The resonant frequency is at 66.67 kHz for the first prototype.

The AC current in the primary planar coil generates a magnetic flux transferring the energy to the secondary planar coil, which is placed on top of the primary coil outside of the PV module as shown in Figure 5. Then, the inducted AC current is rectified using an active rectifier.

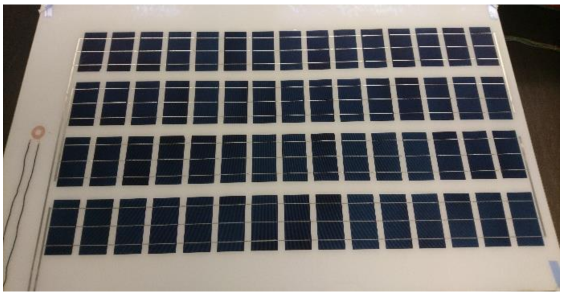

Figure 3: The picture shows the PV module with 60 half-cells and the integrated planar coil.

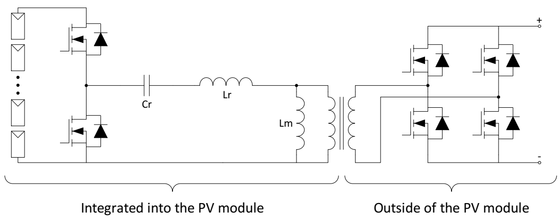

Figure 4: A LLC resonant half-bridge power converter is used for the new PV system concept. The electronic schematic shows additionally the active rectifier that is needed for the DC bus solution at the output.

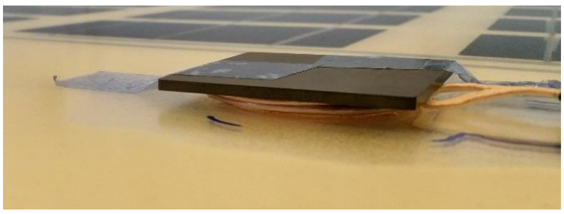

Figure 5: The secondary planar coil is placed on top of the primary coil. Under the primary coil behind the backsheet and on top of the secondary coil, there are two ferrites for a better conductivity of the magnetic flux.

3 MEASUREMENT RESULTS

A first prototype of a LLC resonant half-bridge power converter could be manufactured according to Figure 4. First measurements were performed using DC power supply connected to the input of the resonant converter. The maximum efficiency was 88.2 % at an output power of 207 W [7]. Figure 6 shows additional measurements results for other operating points.

These measurements were performed on the very first prototype without any optimisation on the electronic components. Table I shows the calculated losses from the measurements results. Based on that, an efficiency improvement of 4 to 5 % is going to be targeted.

Table I: The losses were calculated from the measurements showing the highest efficiency (marked green in Figure 6) [7].

Components	Losses
Planar coils	3.5 %
Resonant capacitor	1.0 %
PCB tracks	1.0 %
Active rectifier	4.0 %
Half-bridge	2.5 %

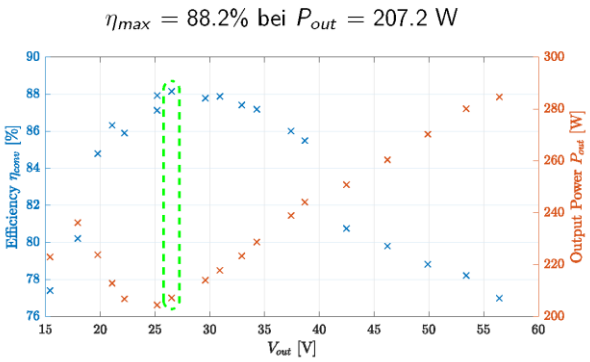

Figure 6: Efficiency and output power measurements were performed for different operating points. The highest efficiency of 88.2 % is achieved at an output power of 207 W [7].

5 CONCLUSION AND OUTLOOK

A first functional model of wireless PV system feeding a DC bus could be presented. The prototype including the LLC resonant half-bridge power converter, the inductive power transmission and the active rectifier was built up and tested in the laboratory. The maximum efficiency of 88.2 % was measured at an output power of 207 W.

The next steps is to integrate the resonant converter into the PV module. Therefore, different PCB packaging techniques need to be analysed e.g. embedded component packaging. The new wireless PV module will paired with a clickable mounting system [6] in order to decrease the overall PV system costs. This should enable launching a new product that allows a cost-effective installation with minimum maintenance effort.

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