"URBAN PLANT" light-weight Solar System FOR PARKING AND Other URBAN DOUBLE USE APPLICATIONS

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ABSTRACT: Innovations on all aspects of BOS and solar cell integration into the module are essential to further reducing the costs of PV electricity and substantial progress has been made in the past years. One other important aspect is the availability of space for PV power production, especially in densely occupied urban areas. Roof space is limited or only partially useable. A promising other application for PV power production in urban areas today are PV carports on parking lots, which require massive structures and foundations. The approach presented here is a newly developed PV plant which automatically stores the PV modules in a protection box in case of bad weather conditions. Avoiding bad weather conditions implies that only a fraction of the mechanical load is present on the PV modules and the structure, enabling light weight structural design. The newly developed PV plant is folding the PV generator into a protection box and will pull out the PV generator, carried on two supporting cables for operation during good weather conditions. An innovative autonomous control system was developed based on local meteo sensors and regional weather information. The PV modules of the Urban Plant are mounted six meters above a parking lot with the benefit of full double use of the land below. Thus a PV system has been built with currently 52 kW nominal power, 16 meter wide, with a folding roof of PV modules expanding 24 meters in one direction. The system can be extended to 104 kWp with a second folding roof expanding into the other direction. As special PV system design was developed with a light weight PV generator using module laminates with special mounting elements. Moreover the system comprises innovative string wiring and inverters that can be also integrated into the safety box. A first 250kW commercial system is scheduled to be set into operation in Jan 2014 in Southern Germany.
Keywords: BOS, mounting structure, PV carports

1 Introduction

Cost reduction of PV electricity was done in the last two decades mainly by reducing the costs of the PV module by about a factor of ten.[1] The other Balance of System (BOS) costs have also been reduced, but to a far lesser extent. Today, grid connected PV electricity cost reduction is primarily limited by the BOS costs. Thus, optimizing of module efficiency is today a top priority for module manufacturer focusing not only to reducing the modules €/Wp costs itself, but also decreasing the area related BOS costs.

Today standard mechanical mounting costs for large flat roof PV systems are about 15% for hardware expense (Fig. 1 and Tab. I) and about 15% labour. Together with the 10% for the inverter this traditional BOS components sum up to 45%, the same value as the cost for the PV module. Within the module cost share, the dominant part is the c-Si solar cells including poly silicon followed by the module manufacturing costs.

There is still a substantial potential for cost reduction by including not the standard framed PV module into the mechanical mounting structure, but integrating the module laminate into a mounting structure.

While roof mounted PV systems have in several Southern markets already generation cost below the energy purchased from the grid, PV production remains limited to the available roof space, because especially in urban areas rent of land is too expensive for ground-based solar plants. Double-use of land, PV power production above and for example parking below is an alternative to overcome this dilemma. However, if the modules are simply installed several meters above ground a costly carport-type construction with heavy foundations is required to withstand all weather conditions.

Other methods to mount PV modules on cables were developed recently. A cable based one-axis tracking system of 650kW was realised on top of a land-fill site. A second cable-based two-axis tracking PV system of 90kW with modules 8 meters above ground covering an industrial outdoor storage facility, where trucks are able to pass underneath was realized in 2010.[2] In 2012 the worldwide first ski-lift was equipped with a 60kW cable-based one axis PV system. All these projects offer the potential of double use of land, on top of existing infrastructure areas.

The goal has been to develop a new modular PV plant category where the PV generator and the mounting structure have a minimal weight to be able to reduce BOS costs significantly. The innovation to achieve this goal presented in this paper has been to avoid extreme forces by wind, snow or ice acting on the system, which offers several advantages and substantial potential for the implementation of cost-effective light weight design.

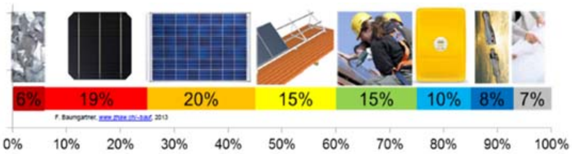

Figure 1: Cost share of 200kW PV roof top system investment in Switzerland 2013.

Table I: Cost share of 200kW PV roof top system investment in Switzerland 2013

System component	Cost share
PV module	45%
Fixed mounting hardware	15%
Mounting labor	15%
Inverter	10%
Electrical AC inst., approval	8%
Planning, others	7%

2 DEVELOPMENT OF A FOLDABLE PV MOUNTING STRUCTURE

2.1 Avoid weather related mechanical overload

All worldwide PV installations built today expose the PV modules to extreme wind, snow, sand storms and other hazardous environmental conditions, should such conditions occur. Based on that, module test and qualification standards were developed and are still improved. For example a mechanical load of 2400 Pa is applied during the standard IEC 61215 module qualification test, which is equal to the static wind pressure at a wind speed of 58 m/s (209km/h). The ASTM E1830 even tests for static 5400 Pa to simulate heavy snow and ice accumulation on the PV module front surface. Secondary the mechanical system to mount the PV modules on top of a roof, have to fulfil the local grid codes for buildings.

For example the wind load is developing by a power of two with the wind speed (Fig. 2). But most of the time the operation of a PV plant is done not at highest wind load conditions. The mechanical mounting structure of a fixed installed PV module has to be designed in a way to hold out the highest gust of wind at the plant location.

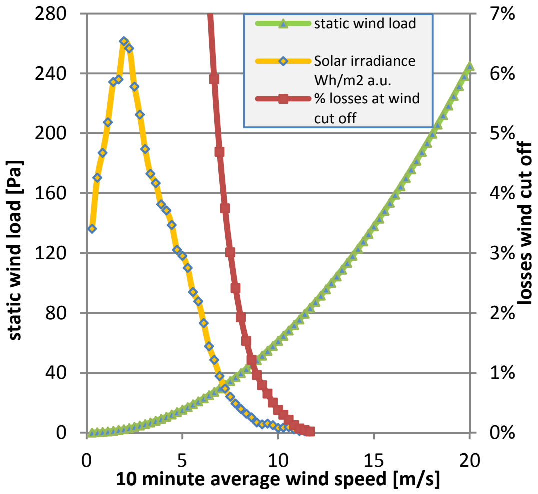

Figure 2: Mapping of the solar irradiance versus wind speed, static wind load and losses due to power off at certain wind speed threshold for location Vaduz, Liechtenstein.(average wind speed 2 m/s from 2004 2008)

The weather protection system of a flower is different. It unfolds typically at sunny conditions. (Fig.3) The central idea of the presented new PV mounting concept is to implement this folding process of a flower. Approach to develop Urban Plant:

- The PV module is moved into a protection box at extreme weather conditions
- Thus costs will be reduced due to much lower requirements of wind load and exclusion of hail and heavy snow - less material of the mechanical mounting system and fundaments is needed
- A modular approach from several 50 kW to MW with reduced requirements for local installation, with flexible distance of fundaments and pillar placements
- Double use of land, by mounting the PV modules in several meter on top of e.g. a car parking area; Agro Photovoltaic on top of a building [4]

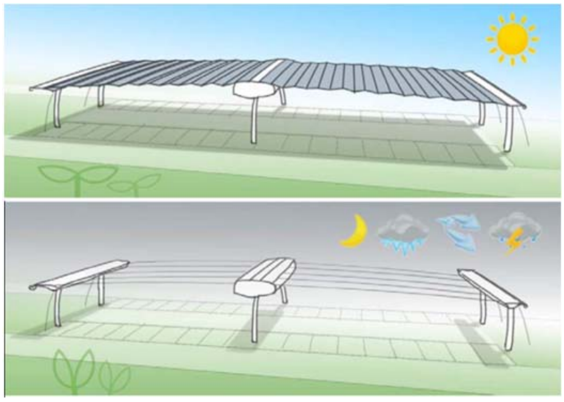

Figure 3: Sketch of the functional principle of theUrban Plant with operation (top - sunny) and standby mode (bottom - heavy wind, snow, sand storm).[9]

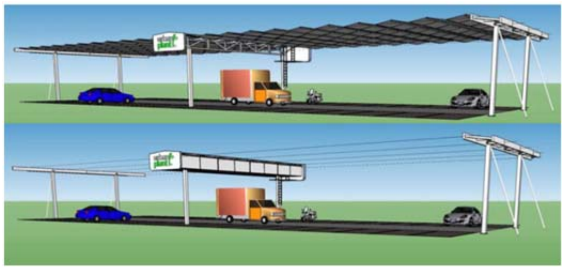

Figure 4: Sketch of PV electricity production on top of a carport by Urban Plant; regular operation (top - sunny) and storing the PV generator under extraordinary weather conditions, heavy wind, hail or snow.(bottom).[9]

2.2 Design process for wind load calculation

Based on CFD Computational Fluid Dynamic calculations several mechanical load conditions were calculated.[3] The highest values of the mechanical load onto the PV mounting structure was found in the sector where the two trucks were parked underneath. (Similar to Fig. 5) But the finally calculated 210 Pa load at 12m/s wind speed is still ten times smaller than the typical test load for standard PV module under IEC 61215.

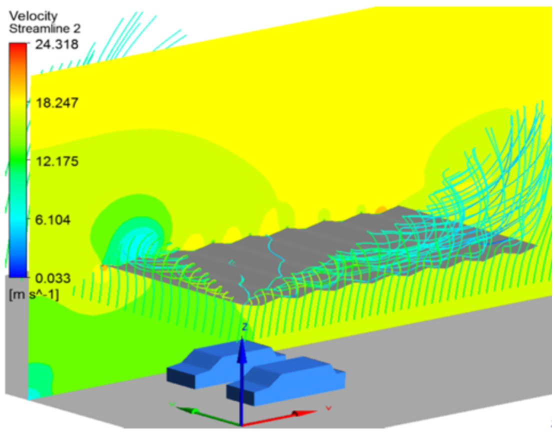

Figure 5: CFD wind load calculations of Urban Plant around two passenger cars parking below and near the corner of the plant.[4]

2.3 Control strategy of safety mode operation

During the joint scientific project ZHAW develops methods to find the optimum time to start the safety mode operation. The goal is to base that individual activation decision on locally measured weather data, like wind, temperature and others from the sensor on top of the protection box. Additionally in same special weather conditions also regional weather information is taken into account.

It is important to reduce the losses of PV electricity production due to premature activation of the safety mode. Due to the fact that the current design requires approximately one minute to bring all modules from the extended position into the protection box, an optimized algorithm to predict the wind speed for that time window is needed.

The developed algorithm has to outmatch a simple control at constant wind speed threshold.

Several measured data sets for different location were analysed form standard 10 minute average wind speed and maximum wind in that 10 minutes. Advanced measured wind data in the second resolution was analysed to learn more about the prognosis of the wind speed within the next minute.

Losses in PV electricity production are between 0.5 and about 5% for different location in Switzerland, if loss analysis is based on the 10 minute average wind speed and at a constant threshold of 8 m/s. Thus all 10 minutes interval were the wind speed exceeds that level are counted as losses. But if the average wind speed is below 8 m/s the maximum wind speed my by larger sometimes twice that level depending on turbulences. Making the same loss analysis based on the maximum wind speed values in the 10 minute interval the losses are about the same if the wind threshold levels is set to a much higher value of about 14m/s. By analysing wind in one second intervals and weather data from Vaduz, and applying different algorithm it is expected that the total annual PV electrify losses have to be greater than 1.5% but may be around 3% at a wind speed turn off threshold varying around 10 m/s.

3 RELIZATION OF FIRST URBAN PLANT

3.1 Development process

The total system consist of the PV modules, movable along the supporting cables, the steering cable pulling the PV modules by the use of an electrical motor and the control system based on metro sensors and weather information and the supporting structure of the protection box and the end pillar.

The actual design is built on individual PV modules (1m x 2m, 72 c-Silicon cells 6”) connected electrical into serial (36 modules in one string) and powering the PV. The inverter is also integrated in the protection box, four meters above the ground.

During the activation of the safety mode an electrical motor pulls the PV modules into the protection box within approximately one minute. The Urban Plant is equipped with an UPS uninterruptable power supply to feed the electrical motors and the control electronic in case of external AC power failure.

The main development processes are:

- Module - Mounting
  Mechanical integration of glass/c-Si module laminate to the foldable mechanical mounting structure
- Steel structure with fixed cables and actuator
- Cable-based string mounting including electrical drive and steering cables
- Control of operation, activation of the standby mode, due to weather condition based on unique algorithm [3,4]
- Electrical PV string layout
- PV Inverter placement in the protection box
- Mechanical supporting structure

3.2 Experimental Indoor model

In spring 2013 the first indoor prototype was installed to test different types of module mounting methods. The focus was also to optimize bearings at low friction losses on top of the mounting cables. Also different methods of applying the steering cables were developed and endurance testing was performed.

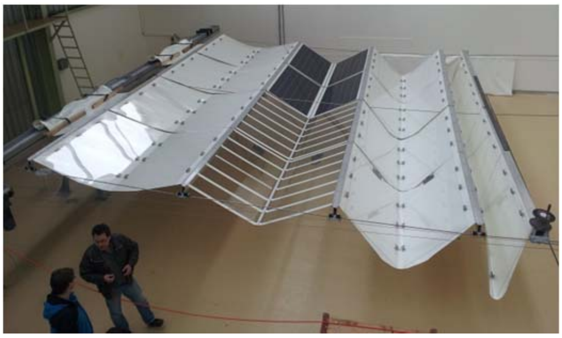

Figure 6: Urban Plant indoor model

3.2 Outdoor 52kW Prototype

The first outdoor prototype was realized in June 2013 in Blazers Liechtenstein.[5] Tests are performed on the cable-base mechanical system including electrical drives and safety mode operation and control.[3]

3.3 Product sizing – flexible modular design

Urban plant is designed as a modular PV power plant with multiple 4 m square 22 m foldable PV generators each mounted on cables. The UP50 prototype installed in Blazers consists of four such elements sum up at 52 kW nominal power. Several hundred kW UP installations composed of several UP50 or UP100 subunit.

Table II: Urban Plant nominal power data

	Pn[kW]	length[m]	width[m]
UP50	52	25	16
UP100L	104	50	16
UP100W	104	25	32
UP200W	208	50	32
UP200L	208	100	16
UP400	416	100	32

3.4 Urban plant – PV Carport

Recently the results of a potential study of available PV power on top of existing parking space ware presented.[7] The analysed typical Swiss medium-sized city was Frauenfeld, a town with 22 665 inhabitants. The potential of 5.4 MW PV power covering these parking lots alone would feed the electricity demand of 1981 city's passenger cars. The appropriate 49 larger parking lots in Frauenfeld cover an area of 125 140 m² to provide parking space for about 4240 cars. That study was based on conventional PV carports on the market, with about 2kW PV power on top of each individual parking slot. They cover typically only the area of the car-slots, but not the access road. Using Urban Plant the whole area is available for PV use. Thus the Ground Coverage Ratio (GCR) of installed PV power on the available total area will be increased from the 60% found in above study to 90%. In average Urban Plant offers about one third more PV power by also covering the access roads of the total parking area.

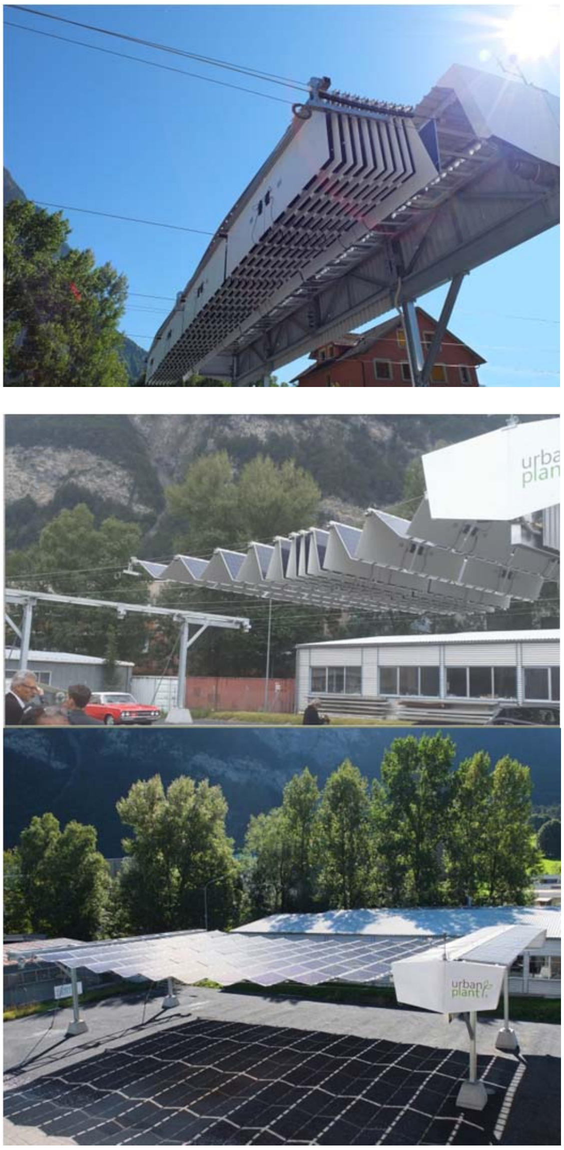

Figure 7: Urban Plant UP50 Prototype operating since June 2013 (16m x 25m and 54kWp).

In the case of solar carports, one has to install not only the PV elements but also the base construction of the carport itself. Hence, the investment cost is slightly higher than in the case of PV modules that are fitted on existing roofs. Due to snow load and heavy wind load these traditional PV Carports need up to 3 tons of fundaments for each individual parking space. The benefit of Urban Plant compared to traditional PV carport products is less investment into fundaments because the snow and heavy wind load is avoided.

3.5 CO_2 Footprint

The light weight design of Urban Plant results in savings of material consumption of about 90% for concrete and aluminium compared to traditional PV Carports (Tab. III) Taken into account that the Urban Plant requires also steel, compared to a traditional aluminium PV carport, the final benefit of reduced primary energy demand and thus CO_2 emission is reduced by about two thirds. Additional cost savings are found in using in total less material during the construction phase including transport.

Table III: Urban Plant's material consumption in kilogram in comparison to conventional PV Carports

	Urban Plant [kg/kW]	conv. PV carport [kg/kW]
glass	56	56
aluminium	15	120
steel	66	0
concrete	75	890

Figure 8: Urban Plant UP 50 in Balzers (Top power and shade; bottom a truck is passing below the PV plant.

4 DISCUSSION AND OUTLOOK

A new type of light weight PV plant is presented to be installed on top of existing infrastructure areas, like

parking space or on top of buildings.
The key elements of innovation are:

- Double use of land on top of a PV carport with a minimum of needed pillars covering also the access roads with PV power
- Less weight, less costs for PV module mounting structure and fundaments
- Light weight PV module laminates are integrated without the extreme load restriction of heavy wind, snow and hail
- Innovative control system based on local meteor sensors and regional weather information's is implemented
- Reduced manpower in mechanical and electrical installation at the plant site needed, due to modular design and the pre-fabrication of the PV generator including the electrical installation of the PV inverter in the protection box

In spring 2014 a UP200 will be installed on top of an industrial parking area in southern Germany. Several UP50 units will be tested as prototypes on top of flat roof buildings. For example, a modified UP50 on top of the Technopark, Winterthur building is planned to be installed in 2014.

Intensive planning is going on to verify the implementation of Urban Plant cover agricultural land. Again Urban plant has the potential to combine PV electricity production and agricultural usage of the same are to benefit in double use of land also outside the urban area. [6]

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