URBANBOX THE LIGHTWEIGHT RETRACTABLE PV PLANT

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ABSTRACT: Recently a study of Swiss utilities showed a Photovoltaic (PV) economic potential of 3 GW and a three times higher technical potential on classical infrastructure areas in Switzerland. Therefore, there exists a large opportunity for suitable dual-use PV systems. However, the requirements, such as long span between foundations, investment cost and operating cost for cost-effective power production have been challenging for existing fixed roof type solutions. The retractable URBANBOX PV Roof is a new approach, offering light weight design for the structure and foundation, integrated automated PV module cleaning and a modular factory-prefabricated box concept for the storage of the PV carriers, drives and controls. In 2022 the URBANBOX demonstration system was installed in Liechtenstein and test results and result of a research project for further optimisation of the lightweight structure are presented in this paper. They include the optimization of steel for the mounting structure (<70 kg/kWp) for the URBANBOX prototype to be built in 2024. This project also investigated and developed a built-in automatic panel cleaning system and weather-based control algorithm for the retraction of the PV module carriers.
Keywords: PV Module Mounting, retractable PV Plant Systems, automated PV panel cleaning, BOS, Innovation, Soiling, Testing, long span PV structure

1 INTRODUCTION

Globally, the demand for PV power plants is unbroken and the potential for infrastructure areas will also have to be raised for the renewable electricity hunger, as the buildings are not sufficient. Recently, the Swiss Association of Electricity Companies estimated the PV potential in Switzerland at 3 GW on infrastructure sites, which is slightly less than one tenth of the total PV expansion potential [2]. The same authors have also recently calculated the potential for PV carports at 6 to 10GW, i.e. double or triple the above potential [3]. With a nominal PV power of about 2kWp per parking lot in a typical Swiss medium-sized city of 23 000 inhabitants PV carport on medium and large parking areas will account for 5.3MW PV power [4].

Successful PV innovations overcome the bottleneck of the rising cost shares in state-of-the-art photovoltaic power plants. This rising cost share is not found in the photovoltaic module itself but in the mounting, cabling system and the installation process, summaries as Balance of System (BOS). In the last decade global photovoltaic module prices declined by a factor of ten due to economy of scale in the fabs. But the BOS costs do not change so much. Therefore, in the period 2013 to 2019 the cost for PV modules and inverter decreased by one third from 55% to 37% of share of total plant costs in Switzerland for larger rooftop PV plants between 100 to 300kW in power. Reducing BOS costs is a global trend, and it calls for substantial innovation in and new system approaches. If the fixed PV module mounting structures are reaching the marginal material cost limits of metal and concrete, new BOS systems must be developed. Today's PV carports with fixed support structure, typically require up to 200kg of metal and about half a ton of concrete per kW PV power, resulting in double to triple the construction costs compared to industrial roofs [4]. This calls for new systems using a minimum amount of metal used in the mounting structure, and not only innovate one part.

In recent years, projects have been implemented in Switzerland to investigate the potential of mounting modules on steel cables in order to save the amount of metal. This was combined with single and dual axis mechanical trackers and the successful power supply of a ski lift was demonstrated (Table I).

Table I: Experience with dual use PV mounting projects initiated by the co-authors [5,6,7].

Year		PV Power
2009		648 kWp Lonza Solarpark, Waldshut, Germany
2011		70kW, Solar Ski Lift, Tenna, Switzerland
2013		20kW Light Energy Plant, Balzers, Liechtenstein
2022		50 kW URBANBOX Bendern, Liechtenstein

In 2013, with the development of a retractable PV module system, as is common in a similar form for shading in and on buildings, the static PV mounting was deviated from for the first time, even for higher PV power. This reduces the maximum mechanical loads caused by wind, hail and snow, as the modules are retracted in a protected area during these weather conditions. The current paper is the first to present a different retractable PV module system, where the modules are stacked on top of each other in a box rather than folded as they were a decade ago, with potential economic benefits.

2 URBANBOX CONCEPT

In the current URBANBOX prototype, 12 PV module carriers, each with 10 PV modules can be stepwise horizontally extracted onto the solar roof and retracted back into the buffer box, where they are vertically stacked [8]. The carriers move on a steel guide rail, and they are designed to be fully compatible to standard mainstream PV modules, a big advantage, when compared to other retractable PV system solutions (Fig. 1).

Figure 1: Top view of the URBANBOX demonstration system installed in 2022 in Bendern Liechtenstein.

Table III: Technical features URBANBOX demo system and future prototype/commercial URBANBOX systems

PV Power		
	Demo2022	Prototype
Number of PV carriers	12	up to 20
Power per carrier (kWp)	3.7	4.3
Power on roof of box (kWp)	6	5
Power of plant (kWp)	50	80 to 91
Dimensions		
Length (m)	28	up to 38
Width (m)	11	11.7
Ground clearance (m)	4.5	4.5
Automatic PV module cleaning	YES	YES
Structure	Wood	Wood/Steel
Foundation	Screw-type	Screw-type, other

Based on the experience of the 2022 demo system in Bendern the prototype solution 2024 in the way to the commercial system will lead to a lightweight construction of 70kg steel used per kW PV power for 20 carriers each equipped with 10 PV high efficient commercial modules at a plant power of 85W for each URBANBOX (Table II).

3 LIGHTWEIGT CONSTRUCTION

The technical requirements for the structural mechanical design result from the reduced wind and snow loads due to the principle of retraction and the long-term reliability of the moving parts (Fig. 3). The consideration of corrosion and soling for the longitudinal movement of the module carriers led to sectional steel/sheet metal profiles that are placed on wooden longitudinal beams as structural elements, while complying with the economic framework conditions. Thus, wood as a renewable building material is primarily used in the housing and base construction (Fig. 2). The classical consideration of bending stiffness, mechanical bending and tensile stresses have been applied and maintenance-free and low-wear drives are used. This results in a steel input of 41kg/kW for the module support and 29kg/kW for the remaining metal support structure, which will be integrated into the wooden construction of the URBANBOX prototype to be realised in 2024.

Figure 2: Wood is used as relevant construction material in the URBANBOX base construction.

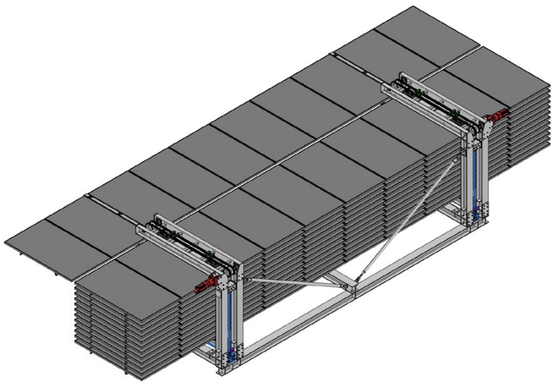

Figure 3: URBANBOX Concept of horizontal and vertical PV module movement.

It is important to point out that such systems can be realized in a similar light weight design also in hurricane regions with extreme wind conditions, because only the small area of the structure itself is exposed to the elements, but not the large surface area of the solar panels.

4 AUTOMATIC PANEL CLEANING SYSTEM

Soling may strongly depend on the location and may reduce the PV output by several percent. The natural weather cleaning effect also depends on factors like inclination of the PV modules and density of rain or snow for example. One of the most comprehensive studies of state of the art in soiling in PV is given by the resent IEA Task 13 Report 2022. They estimated on the studies that soling losses will leading to subsequent financial losses in the range of four to seven billion euros by 2023 on the global scale based on 4-5% energy production losses [9].

4.1 Rotating brush cleaning system

A key element of the URBANBOX concept is a simple, in-expensive implementation of fully automated high quality PV module cleaning [8]. The development of the appropriate hardware and process technology of cleaning was studied within the ongoing Innosuisse research project 100.944 IP-EE and led to the brush-based solution without artificial water supply. With indoor and outdoor tests, the final solution was found with a brush diameter of 180mm (Fig. 4). Good results were achieved with rotating speeds between 100 and 500rpm at low horizontal speed (3 to 6 cm/s) of passing carriers. The frequency of cleaning, whether it is on a weekly basis and depends on rainfall, is still in the development phase and is primarily based on tests carried out with the first URBANBOX demo system in Bendern. Moreover, cleaning tests are planned with the rain sensor installed on the system, allowing also the use of rainwater on the panels for optimized cleaning.

Figure 4: -The rotating brush is placed on the top of the PV module carrier entrance of the box.

The irradiation losses during the cleaning process can be neglected, as the algorithm selects low irradiation periods below 50 W/m^2. Thus, due to the low average degree of soiling achieved by the automatic cleaning, even stubborn layers of dirt repeatedly dried by dew and dust can be significantly avoided.

Together with the Soiling sensor and in particular its sensitivity and reproducibility, these cleaning operations can be reduced even further, eliminating the need to schedule service activities for an operating life of 25 years for typical applications in Central Europe. In this region, the use of automatic URBANBOX cleaning is therefore expected to result in a PV yield gain of 1 to 5% compared to conventional uncleaned systems.

It is important to note, that the new fully integrated cleaning system has particular relevance for arid regions such as Middle East countries, Southwest USA, parts of India and many other regions, where dust, sometimes in combination with due, represents a big problem for PV and mandate frequent costly PV panel cleaning especially for dual-use PV system with high ground clearance. This serious problem is greatly alleviated with URBANBOX because the panels are be wiped off in the evening, protected to a large extent from dust and due during the night in the box and cleaned again in the morning when the carriers are extracted onto the structure.

4.2 Development of integrated soling sensor

The performance of the most proven commercial dust /soling sensors have been analysed recently in [9] but with their typical costs of 3000$ and more, will not fit into economics of URBANBOX. They mostly use the optical principle of transmission change and are partly equipped with complex image recognition and self-calibration techniques and achieve a measurement uncertainty of no less than 1%.

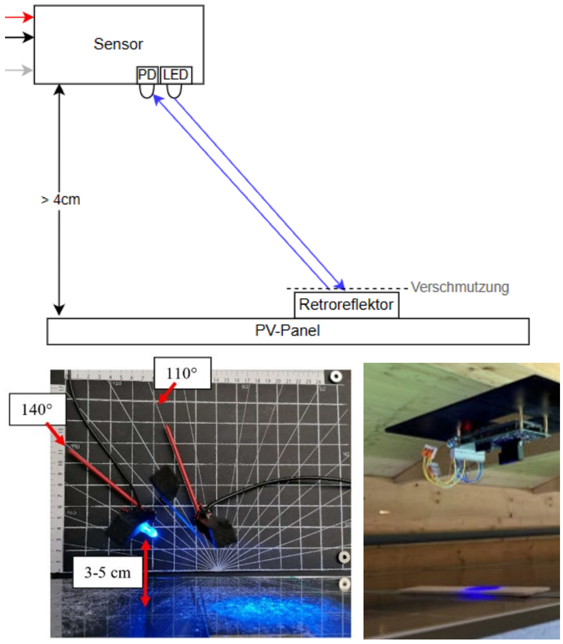

Figure 5: The optical reflection of a blue LED light is measured as the functional principle of the soling sensor and the indoor experimental test setup and the position within the BOX on top of the PV module is shown in the photographs below.

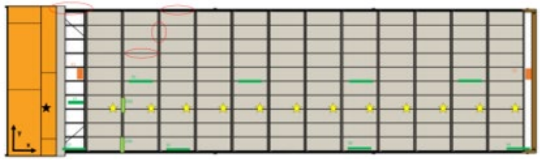

Figure 6: In yellow the position of the different reflectors for the blue light is shown mounted between tow PV modules on each carrier.

Within the research project ZHAW developed an optical dust sensor and tested a first version in the URBANBOX demo system. The optical sensor head contains both the LEDs and the photodiodes, the structure of which concentrates the beam path from the transmitter and receiver (Fig. 5). The optical reflector, whose soiling is measured, is placed in the area between two PV modules and passes the optical sensor head when the carriers are automatically moved in and out (Fig. 5).

To reduce stray light from outside the box, the drive current of the blue LED was modulated with a carrier frequency of 1280 Hz and the signal of the receiver photodiode was filtered with a bandpass filter after Opamp amplification. The self-calibration, processing of the output variables and communication with the URBANBOX's PLC control unit are carried out by an integrated microcontroller.

The sensor concept has proven itself in the first tests and was able to achieve deviations in reproducibility of typically one percent.

5 WEATHER BASED CONTROL

The local weather sensors, such as wind, rain and snow sensors, mounted on the URBANBOX currently provide the input variables to control the entry and exit of the PV carriers using a robust algorithm. To develop the algorithm, various historical weather profiles, wind and solar radiation were analyzed, with the results from three locations in the Switzerland being presented here. The locations are in the Swiss plateau near cities which does not include a mountainous region and include weather data that is available every second over three years.

The results of a simple, robust algorithm will be presented here, which switches to the retraction state at a wind speed threshold of 12m/s and automatically extends again when the wind speed falls below 10m/s with a hysteresis time of 15 minutes if the irradiation is above 50W/m^2.

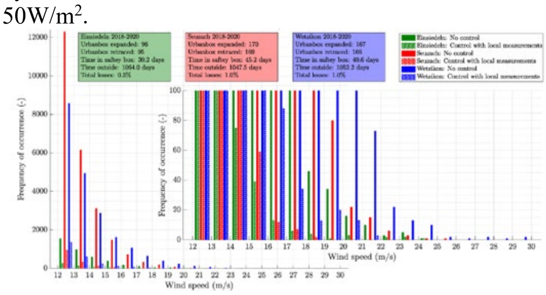

Figure 7: Histogram of wind speed for three locations in Switzerland.

The solar yield losses are less than one percent. Due to this algorithm, 33, 55 and 56 additional trips (Fig. 7) can be expected for the various location Einsiedeln, Wetzikon and Seuzach, every year. During these retraction processes, gusts of wind can affect the partially exposed PV module carrier with max wind speeds of 25, 22 and 19m/s.

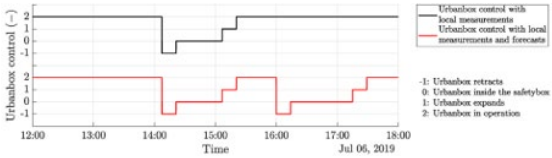

Figure 8: Time course of the states of the retraction process of the module carriers with and without weather forecast.

Tests using cost-effective weather forecasts available today have not resulted in a significant improvement in wind exposure, but have significantly increased the number of trips, which is not conducive to the longest possible operating time of over 25 (Fig. 8).

The URBANBOX system is already configured with a commercial monitoring system, with cloud data processing, monitoring 24/7 the sensors on the system states variables and the drive hardware and PV performance. Moreover, alarms by email are automatically generated, if the actual parameter differ from the pre-set parameters range. For the URBANBOX 2024 prototype a new weather control algorithm combining local weather data with area specific weather forecast data is planned to control the system from the cloud storage solution and further enhance the performance. Moreover, future URBANBOX systems installed nearby my exchange data via the cloud solution for instant monitoring and control.

6 RESULTS AND OUTLOOK

The automatic cleaning system of the URBANBOX brings economic advantages over locations with high pollution, such as dry agricultural areas with up to 11% solar power losses per month, as well as desert areas. [9].

The fact that the URBANBOX can be set up and fully tested in a fully functional way indoors at the production site with specialists, and that no specialists are needed for the installation apart from the suppliers, opens relevant advantages of binding delivery at the most diverse locations in times of great shortage of skilled workers.

The limitation of the use of metal to, for example, 70kg per kW for the URBANBOX undercuts the requirement for fixed assembly solutions with a comparable height and span by a factor of 2. This enables raw material costs to be minimized, which become more important with green steel, and helps produce solar electricity with a small amount CO_2 rucksack to reach.

With increasing climate change, the risks of local storms are rising, which very often lead to damage to fixed PV parks that is usually not covered by insurance.

Investors who require a reliable power supply and who are concerned about preserving the value of their investment could take advantage of the protected solar modules in the URBANBOX when it is retracted in safety mode during a storm or hailstorm.

Further development of the URBANBOX in combination with integrated battery storage allows the construction of an off-grid power supply, which can contribute to disaster relief operations, charging stations for electric vehicles in remote areas or the supply of settlements, for example.

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REFERENCES

[1] L. Grüter, C. Nikiforos, S. Probst, L. Konersmann, Solarstrom auf Infrastrukturanlagen und Konversionsflächen, Energie Zukunft Schweiz, 23.07.2021; https://www.energiezukunftschweiz.ch [Online: accessed 12.09.2023].

[2] M. Hochreutener, L. Grüter, C. Nikiforos, L. Konersmann, Solarstrom auf Parkplatzüberdach-ungen, Energie Zukunft Schweiz, 04.05.2022; https://pubdb.bfe.admin.ch/ [Online: accessed 12.09.2023].

[3] H.-M. Neumann, D. Schär and F. Baumgartner, The potential of PV Carport, Prog. Photovolt: Res. Appl. (2011) DOI: 10.1002/pip.1199

[4] M. Loup, C. Allenspach, H. Hofmann, R. Vogt, F. Carigiet, F. Baumgartner, KEY PERFORMANCE INDICES OF PHOTOVOLTAIC CARPORTS, In Proceedings of the 38th European Photovoltaic Solar Energy Conference and Exhibition (EUPVSEC). WIP Renewable Energies, online, 2021, poster; 6CV.4.31

[5] F. Baumgartner, Arthur Büchel, F. Carigiet, T. Baumann, R. Epp, A. Wirtz, A. Huegli, U. Graf, In Proceedings of the 28th European Photovoltaic Solar Energy Conference and Exhibition (EUPVSEC). WIP Renewable Energies, Paris, France, 2013, talk 4CO.12.2.

[6] F. Baumgartner, A. Büchel, R. Bartholet, In Proceedings of the 27th European Photovoltaic Solar Energy Conference and Exhibition (EUPVSEC). WIP Renewable Energies, Frankfurt, Germany, 2015, poster; 4BV.1.60

[7] F. Baumgartner et al., PV Carport, WePo.9.33LN, 6th World Conference on Photovoltaic Energy Conversion (WCPEC-6); 26th Nov 2014, Kyoto, Japan.

[8] Arthur Büchel, world patent WO 2019 144248A1.

[9] C. Schill, U. Jahn et al., Soiling Losses, Report IEA-PVPS T13-21:2022; ISBN 978-3-907281-09-3, www.iea-pvps.org