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Photovoltaics - Highway Roofing

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***Abstract*—*Energy production must become greenhouse gas neutral in order to protect the climate. Fossil fuels, coal power and nuclear energy in times of energy transition must be excluded. Renewable energies are to secure the power supply in the future. Solar energy plays an important role in the success of the energy transition, but space for solar parks is limited. Photovoltaic plants erected on stands over highways seal valuable usable space because one is using an already sealed area and thus no new land will be sealed, which has a direct, very positive effect on climate protection.*

***Keywords*—*Highway; green energy; photovoltaic system; solar roof.*

I. INTRODUCTION

Large-scale solar plants not only disfigure the landscape, but also seal valuable usable space, making the ground airtight and watertight, so that rainwater cannot seep away or can do so very poorly. This huge solar carport over the highways represents a huge potential for green power generation, but there are problems to be solved.

II. WORLDWIDE RESEARCH AND PROJECTS ON THE USE OF SOLAR ENERGY BY MEANS OF PHOTOVOLTAIC SYSTEM OVER THE HIGHWAY

Back in 2013, various researches were conducted on the use of photovoltaic systems as highway canopies in India. To demonstrate the approach to using land and its solar potential, two areas were studied: Ahmedabad-Rajkot National Highway Road and Ahmedabad-Vadodara National Expressway. The total length of the Ahmedabad-Rajkot National Highway Road is 205 km and that of the Ahmedabad-Vadodara National Expressway is 93 km. Two software programmes were used for modelling - Google Earth Pro and PVsyst simulation software [1].

Figure 1 shows a schematic layout depicting an example of a typical national highway. Each lane has a width of 3.5 m, as specified by the Highways Authority of India. The roadside planting of trees is also symbolically shown in the figure 1. Depending on the area available on the road and the size and technology of the solar modules, different configurations can be designed [1].

The Korea Expressway Corporation has installed a photovoltaic system with 2.6 MWp on the roof of a 1.3 km long soundproof tunnel in Gwanggyo, Gyeonggi Province. This is a steel construction with inserted glass for sound insulation and photovoltaic modules mounted on top of it on an aluminium substructure in the grid dimensions of the glass elements (fig.2) [2].

There is another interesting project worldwide, definitely concerning solar energy on highways, but a little "different". A "bicycle highway" between Daeyon and Seyong in South Korea is a sight to behold - or rather, a concept. It stretches over a length of 32 kilometres, is located between two lanes of the highway and not only protects cyclists from the sun, but also generates electricity at the same time (fig.3) [3].

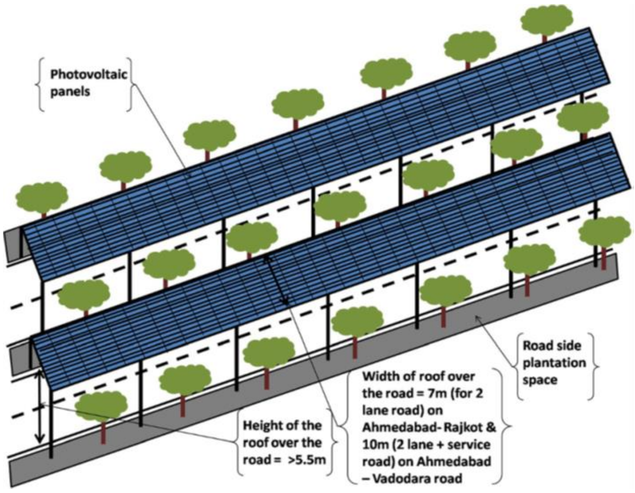

Fig. 1 Schematic illustration of the national road with photovoltaic solar cells on the roof [1]

Fig. 2. Views of the soundproof housing in Korea with attached PV modules [2]

Fig. 3. A "bicycle highway" between Daeyon and Seyong in South Korea [3]

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III. Research and Projects of Solar Roofs over the Highways in Austria, Germany and Switzerland

There are many millions of kilometres of highways worldwide, in Germany alone there are about 13,000 kilometres of highways. Converted to surface area, this amounts to around 312 square kilometres. If these highways were completely equipped with a solar roof (fig.4), more than 45 terawatt hours of solar energy could be generated per year, which theoretically amounts to about one third of the annual household demand in Germany, a country with almost 84 million inhabitants [4].


Fig. 4. This is what a photovoltaic roof for highways should look like one day [5]

In February 2021, a PV road canopy concept was presented, funded under the D-A-CH Cooperation - Transport Infrastructure Research 2019, DACH 2019 [2]. The clients of this project are the Federal Ministry of Transport and Digital Infrastructure, Germany, the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology, Austria and the Federal Roads Office (ASTRA), Switzerland.

Fig. 5. Pilot project of a roof on a sections of highway in the canton of Valais. In 2023, the company Energypier wants to install over 1.6 kilometres of solar panels [6]

According to a report from 01.02.2022, Switzerland is getting serious. The Energy Ministry has announced plans to roof sections of highway with solar cells. Switzerland's energy minister has commissioned the Swiss Federal Roads Office (ASTRA) to make suitable stretches available for the construction of such a roof. Basically, all sections of highway that do not run through a tunnel - about 1,300 to 1,500 kilometres - would be suitable for a roof with photovoltaic systems. A first test of the photovoltaic roof is to start soon in Valais, a canton located in the south of Switzerland. The company Energypier wants to roof a 1.6-kilometre-long section (fig.5), whose solar energy, according to the company, should supply around 12,500 households with electricity per year. Energypier also wants to add wind turbines to the roofs, but this project is still under study, it said. The turbines are expected to provide an additional 30 GWh of electricity annually. Construction of the project is scheduled to start in 2023 [6].

IV. Different Geometric Forms of Solar Roofs

The possible construction forms of the PV roof coverings must meet the technical requirements. The geometric boundary conditions in the road cross-section concern the required clearance. An example of the composition of cross-section elements in Austria with a four-lane road with emergency lane is shown on Fig.6.

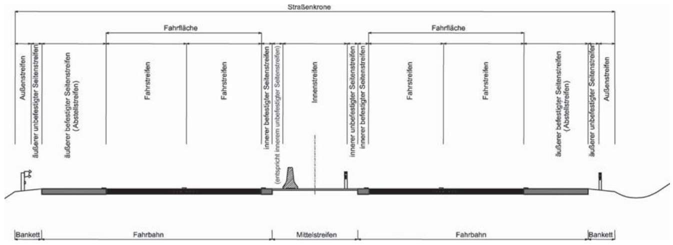

Fig. 6. Example of the composition of cross-section elements in Austria; four-lane road with emergency lanes [7]

The road traffic and clearance area of a highway in Germany can be seen in Fig.7.

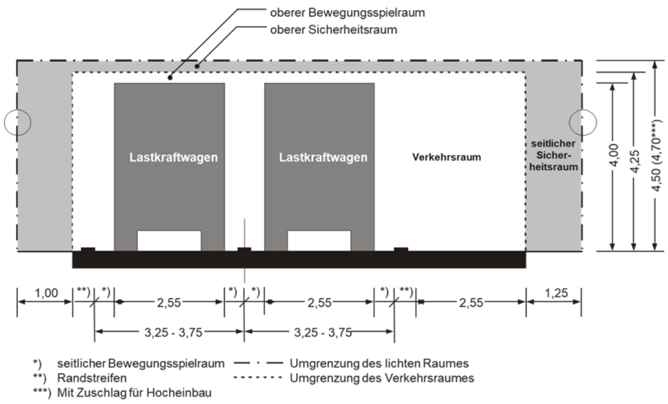

Fig. 7. The road traffic and clearance area of a highway in Germany [8]

Figure 8 shows four variants for the design of the canopy in the transverse direction. The evaluation in the study [2] showed that monopitch roofs as well as gable roofs are suitable for solar roofs over the motorways. The flat roofs have a disadvantage in drainage, however, an energy-efficient elevation of photovoltaic modules could always be realised on these [2].

Four variants are considered for the roofing in the longitudinal direction, whereby the variant with a swivelling roof (4) is ruled out due to its low robustness (Fig.9) [2].

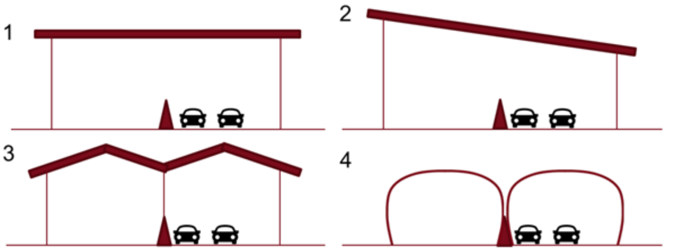

Fig. 8. The variants: a completely flat roof (1), a monopitch roof inclined at an indeterminate angle (2), a gable roof inclined at an indeterminate angle (3) and a roofing with an arched cross-section (4) [2].

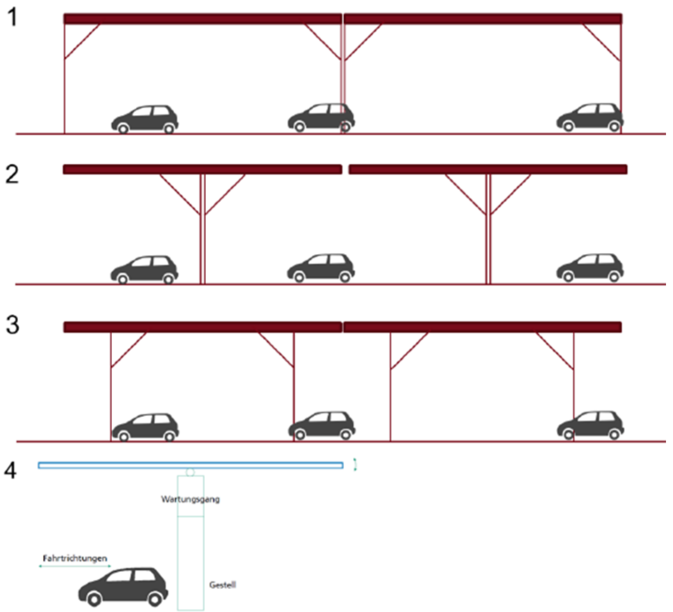

Fig. 9. The four variants for designing the roofing in the longitudinal direction: roofing with supports in the corners (1), roofing with supports in the middle (2), roofing with cantilever with supports in the edge area (3) and a roofing that can be pivoted in the longitudinal direction (4).

V. Ensuring the Safety of Road Users

It is unclear how emergency forces can reach and rescue the injured victims in the event of an accident, for example. We know such difficulties from tunnels. Escape routes must also be possible with a solar roof [4].

VI. Longevity of the Modules

It is also necessary to find out how maintenance-intensive corresponding installations are and how easy or difficult they can be repaired while the highway is in operation, for example if up-shooting debris hits the modules. At the same time, the modules should be able to absorb sound from the "inside" [4].

VII. The Panels Shall Be Translucent

In order not to create a tunnel effect, the solar panels should be translucent. The partially transparent modules are somewhat less efficient, but the difference to conventional cells is only 1%. Not all locations are "ideal" for installing solar panels, such as stretches of highway that are particularly shady, where it would not be worthwhile to install the system. The solar modules must also be aligned correctly to the sun, otherwise the annual energy yield would be up to 20% less than with the same size and at the same location on open spaces where the modules are optimally aligned to the sun [5].

VIII. The Cost of the Solar Panels over the Highway Should Not Be Significant

For the construction of solar roofs over the motorway, massive supports are needed to dissipate wind as well as suction forces, which must also be protected against corrosion. For large-scale power plants, a square metre of photovoltaic surface costs around 125 €; this value alone is likely to be significantly more expensive for motorway roofing [5]. The profitability of a PV roofing investment is significantly influenced by the photovoltaic yield. The yield is offset by the acquisition costs, financing costs if applicable, and the costs for operation and maintenance of the system. The use or sale of the generated electricity is decisive. The respective grid connection point and the consumer structure at the study sites are analysed and included [9].

IX. Potential Problems with Highway Pavements under Solar Roofs

The road surface could turn out to be a problem under the solar roof, because the classic asphalt or concrete is protected from the sun and rain there - but this does not only have positive consequences: a roof for asphalt surfaces is helpful in summer because it lowers the temperature and thus less heat damage such as rutting occurs. However, without rain and the resulting spray from cars, the concrete pavements lose more of their grip because tyre wear then collects and closes the surface. Therefore, the covered concrete roadways would have to be cleaned regularly, which would cause additional costs [5].

X. Design of the PV Roofing

The roofing should be designed to be accessible with access ladders and maintenance walkways, similar to traffic sign bridges. Snow loads, impact loads and wind loads are included in the planning. Possible damage to the load-bearing system due to traffic accidents must also be taken into account, and system failure of the entire structure must be ruled out. The supporting structure is also planned in such a way that it can be expanded modularly in the direction of travel [9].

XI. Influence of the Solar Installations over the Highway on the Landscape

The overbuilding of roads has a significant influence on the landscape. In addition to functional requirements, architectural and design aspects should also be taken into account in the design [9].

XII. Visual Impact of the Construction on Road Users

A PV roof on highways is novel and can lead to possible disturbing optical effects or distractions. The shadows cast by crossbars or supports or the rapid dark-bright change can lead to so-called stroboscopic effects at certain speeds [2]. A stroboscope effect can occur in lighting with discharge lamps and is caused by flicker effects or apparent speed changes in light pulsating through the mains frequency. This causes an apparent standstill or even a reversal of the direction of movement. It thus alters the perception of the course of movement, which can lead to dangerous misjudgements [10].

However, with the planned distances between crossbars and supports of 6 m and a maximum travel speed of 130 km/h, no stroboscopic effect is to be expected because the frequencies of dark-bright alternation are too low [10].

XIII. Other Diverse Requirements for Solar Roofing over the Highways

A photovoltaic construction of this kind should meet a wide range of requirements, for example with regard to drainage and ice formation, fire behaviour, wind and snow loads, stability and impact safety, maintenance options and traffic safety [2, 9].

XIV. Geometry and Materials for the Solar Roofing of the Highways

The concept for the supporting structure provides for a modular construction consisting of self-supporting and founded supporting structure elements, each 10.0 m long, which can then be arranged together in a modular manner to form a system length of up to L = 80.00 m. This ensures that each supporting structure element can bear all loads on its own and that even in extreme cases a system failure can be avoided. This ensures that each supporting structure element can take all loads on its own and that even in extreme cases a system failure of the entire roofing can be avoided [2].

The concept of the supporting structure is designed as a post and beam construction in steel. A supporting structure element consists of two frames (columns/transoms) spanning the road, which are articulated on reinforced concrete foundations with approach bases. In the longitudinal direction (parallel to the road axis), the supporting structure element length is 10.0 m, whereby the distance between the columns is 6.0 m and the purlins project laterally (see Figures 10, 11, 12) [2].

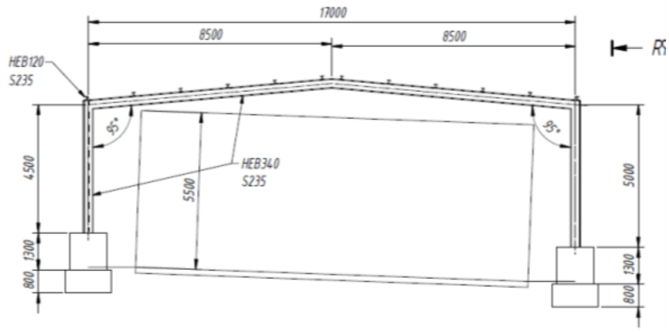

Fig. 10. Design cross-section gable roof [2]

Fig. 12 shows a 3-D representation of the two different structural elements and lateral stiffening and flat foundations [2].

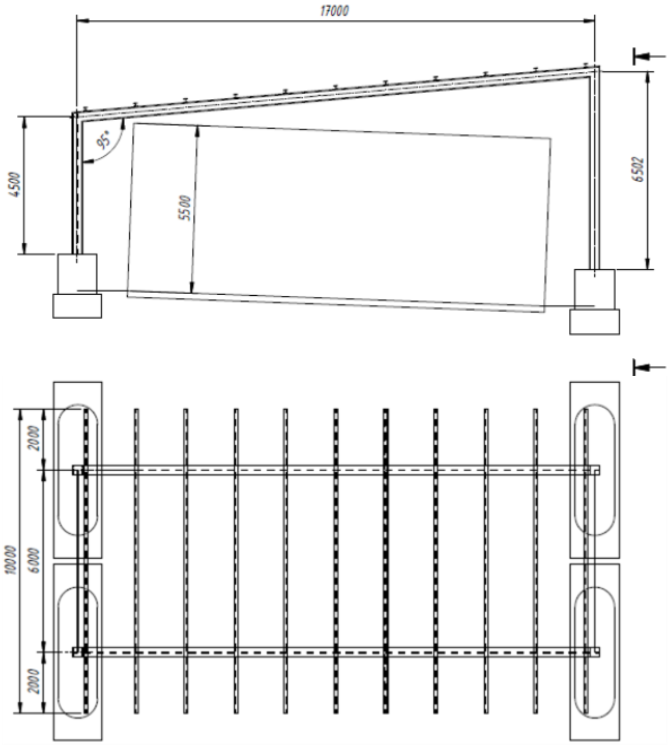

Fig. 11. Design cross-section of monopitch roof (top) Variant of a structural element (bottom) [2].

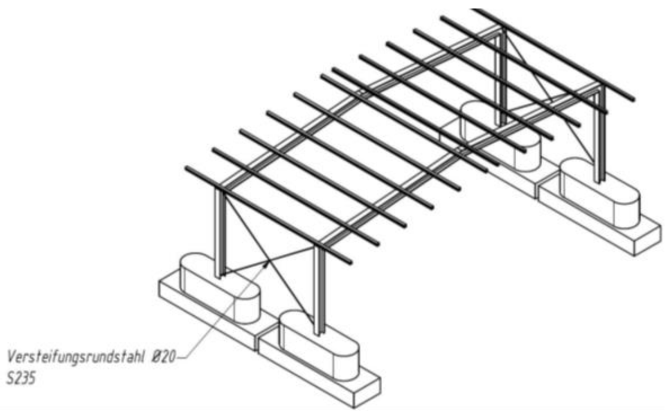

Fig. 12. 3-D representation of the two different structural elements and lateral stiffening and flat foundation [2].

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