Can anti-soiling coating on solar glass influence the degree of performance loss over time of PV modules drastically?

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ABSTRACT: The soiling of photovoltaic (PV) modules is an important issue regarding PV module power output. Depending on the environmental conditions, the different surface structures and anti-reflection coatings, which are applied on the glass in order to increase the annual gain of a PV module, may turn non-effective and glass transmittance may decrease below the level of unstructured or uncoated glass. Former investigations revealed enormous decreases in efficiency due to heavy soiling, up to -80% within a period of 6 month. Therefore, anti-soiling coatings, which aim to reduce these losses, are a very interesting and promising topic.
The market for anti-soiling coatings was screened. Different commercialy available anti-soiling coatings are investigated regarding their functionality, their initial anti-soiling efficiency as well as in terms of weathering stability. A profitability analysis for a simulated 10 MW PV power plant is implemented in regard to the anti-soiling yield gain. The coated PV glazings show different susceptibilities to the soiling test methods. This indicates a variation in wettability of the coatings, monitored by contact angle tests during the intercourse of the study.

Keywords: antisoiling coating, efficiency analysis, energy performance, modeling, degradation, characterization

1 INTRODUCTION

The investigation of the anti-soiling properties and weathering stability of anti-soiling coatings aims to understand the potential of anti-soiling coatings to ensure the highest possible PV module output, especially in arid regions. Therefore the properties of anti-soiling coatings were determined, functionalities and market availability were investigated and an economic profitability calculation for a 10 MW PV power plant was performed.

These steps had to be taken to develop a method for testing and evaluating the efficiency of anti-soiling coatings by reproducible soiling the glass with dry dust in comparison to the in-house-developed wet dust application method [1]. Afterwards, samples were exposed to “artificial rain” to test the self-cleaning effect of the anti-soiling coatings. For the characterization of the samples, FT-IR/UV/Vis spectroscopic measurements are used. In addition to the initial efficiency of the different anti-soiling coatings, their stability towards accelerated ageing tests, including UV-tests and high-temperature tests was investigated.

2 MARKET SURVEY AND ECONOMIC FEASIBILITY ANALYSIS

2.1 Market survey

The aim of the market survey is to find suitable, commercially available dirt-repellent coatings, which provide an energy yield gain over the service life of the system. At the moment, two of the few global players of solar glass manufacturers offer glass with an anti-soiling coating. Requirements for suitable anti-soiling coatings for photovoltaic systems in arid regions are the following properties:

- dust repellent
- weather-resistant
- abrasion-resistant
- highly transparent

2.2 Properties of the anti-soiling coatings

The functionality of anti-soiling coatings is based on two physical principles. These principle effects for the anti-soiling surfaces to remove dust passively are based on hydrophobic or hydrophilic properties, which are respectively water “repellent” or water “attracting”. Water “repellent” hydrophobic coatings have a low surface energy and a contact angle between the surfaces and water above 120° (super-hydrophobic) which is suitable for enhanced cleaning. Materials used for hydrophobic coatings are mainly fluoropolymers.

Water “attracting” hydrophilic coatings have high surface energies, leading to low contact angles and – assuming the presence of enough water - to a closed water film on the surface. With contact angles of less than 10° (super-hydrophilic) dirt particle transportation off the surface is guaranteed under terms of surface inclination. Materials such as silicon oxides (SiOx) and titanium oxides (TiOx) are used for such coatings. Further some hydrophilic coatings do have a photocatalytic functionality being able to directly decompose organic matter after solar activation. This effect will not be in the focus of this study since this is not expected to be of big relevance for coatings in arid climates. For better comparison: the contact angles of average uncoated float glass lies between 20° and 30°.

2.3 Economic efficiency analysis assumptions

Anti-soiling coatings have to be examined to show their economic advantages. Three basic environmental effects are input parameters for the model [Fig. 1] in dependency of the irradiance to show the economic advantage of the coating with a numerical simulation:

- Rain
- Wind / Sand storm
- Dust deposition

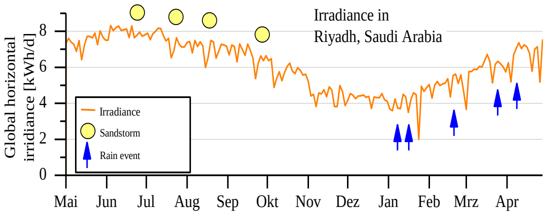

Figure 1: Used reference year in Riyadh, KSA with the irradiance, the rain and the sand storm events.

Assumptions of the climatic factors in arid regions, based on available climatic weather data are made.

i) A sand deposition causes a daily transmittance loss of assumed 0.3%

ii) Sand storms cause a reduction to 40 % and occurs during a reference year 4 times per year, which are observed in the summer month between June and November.

iii) Precipitation, as factor is regarded as positive as long as a "strong" rain event with a precipitation > 5 mm / event occurs. 5 rain events per year are assumed, which are strong enough to clean the surfaces. These events mainly occur during the winter month between January and April. Rain events with less than 5 mm are neglected and have rather negative effects on the transmittance, since particles bond easier to the moist surface.

2.4 Economic efficiency analysis input parameters

The available climatic data from Riyadh, KSA is used for the calculations. Riyadh has a sufficient high solar irradiance (annual global irradiance of 2228 kWh/m²) for the aimed climates with high dust potential. Further the following assumptions are used:

- The daily transmittance loss due to dust deposition is 0.3 %/d.
- The modeled PV plant is an open landscape solar power plant with 10 MW_{peak}.
- The fix costs for the system operation are neglected.
- The service life is set to 25 years.
- The efficiency of the coating compared to non-coated glass is set to 30% less daily dust-accumulation on the surface of the solar system.
- The electricity costs is 0,08 €/kWh [2].
- The mechanical cleaning costs are 0,13 €/m².
- Additionally, the cleaning costs depend on the applied coating, which reduces the cleaning time and water consumption. A total cost reduction of 30 % for coated surfaces is implemented [3]. Additionally it is assumed that the coating causes a higher transmittance after a dust-clearing rain event.

The model targets a maximized annual solar transmittance and a simplified minimal cleaning procedure, which contributes to less water consumption thus reducing the environmental impact. The maximized annual solar transmittance benefits the economic situation of the PV power plant. In the model a reference year, containing the average climatic data (precipitation, wind, solar irradiance and temperature) between 1985 and 2010, is used to represent a typical year in Riyadh, Saudi Arabia.

Three different climatic scenarios are selected for the economic feasibility analysis to determine the potential of the coatings in different climatic situations:

- "Wet": 8 relevant rain events per year, no sand storms
- "Reference": typical average year with 5 relevant rain events and 4 sand storms per year
- "Dry": extreme dry year without relevant rain event and 5 sand storms per year

2.5 Economic efficiency analysis approach

In order to estimate the cost-advantage of anti-soiling coatings compared to the use of non-dirt-repellent coatings in arid climates, an optimal cleaning strategy is determined by maximizing a target value for PV systems, see Fig. 2. The annual monetary profit is used as target value. The target function includes two variables which are non-linear dependent on each other. The model maximizes the target value by searching for the optimal time and interval for the additional cleanings.

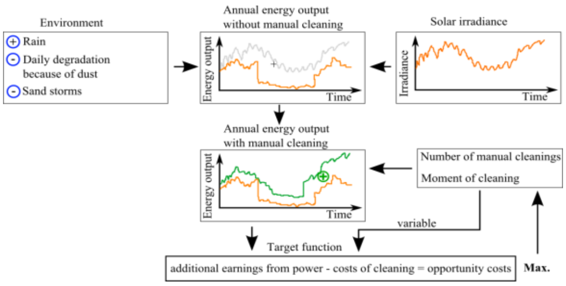

Figure 2: Modeling the economic feasibility of anti-soiling coatings, focusing on 3 environmental impact factors by modeling a whole, e.g. average "reference", year to calculate an optimal cleaning strategy as premise for the beneficial calculation of coatings.

3 EXPERIMENTAL APPROACH

3.1 Selection of anti-soiling coatings

For each relevant functionality type of anti-soiling coatings, one promising product is selected for further characterization and accelerated aging tests.

3.2 Dry dust soiling test

In order to obtain the dust deposition parameter for the economic feasibility study, selected anti-soiling coatings are artificially soiled. The soiling test, developed in-house, for a reproducible deposition of dust helps to determine the dirt-repellent function of the coatings. One sand type (from Dahab, Egypt) with a maximal diameter of 1,5 mm obtained by sieving, is applied from 30 cm height and dispensed as dry dust into the test container. The dust aerosol settles in 3 to 5 minutes on the AS-coated substrates. For the targeted homogeneous and reproducible dust deposition the dust load was determined to 2,05 g/m² with a standard deviation of 0,43 g/m². After the soiling, the coatings are artificially irrigated at an inclination angel of 30° with a 30° inclined spray system built at a horizontal distance of 1,8 m and a vertical distance of 1 m. With 2 minutes of constant "rain-time" 6 mm tap water per hour tested the self-cleaning effect of the samples, which was evaluated by spectral transmittance measurements.

3.3 Dew soiling test

The dew test was performed by first simulating morning dew on the substrate by spraying 1 second a fine water film onto the surface from 30 cm distance. Directly after the moistening dry dust was again distributed and settled on the sample surfaces as described above. The moist-soil-mixture on the surfaces then dried for 30 minutes at room temperature to simulate a sunny mid-day, after the morning dew. The dried soil was then irrigated with the same parameters as used before.

4 RESULTS

4.1 Economic profit

The economic efficiency of dirt-repellent coatings of all three climatic scenarios is calculated with our simulation model (see Table I).

Table I: Economic benefits of the anti-soiling coating

	Uncoated			AS-coated	
	No cleaning [€]	With cleaning [€]	Gain [%]	With cleaning [€]	Gain [%]
Dry year	737.151	1.608.929	118	1.662.640	3,34
Reference year	1.166.546	1.624.244	39	1.676.179	3,2
Wet year	1.322.641	1.629.179	23	1.681.978	3,24

The quite conservative calculation results in additional profits of over 3 % for all scenarios (Fig. 3).

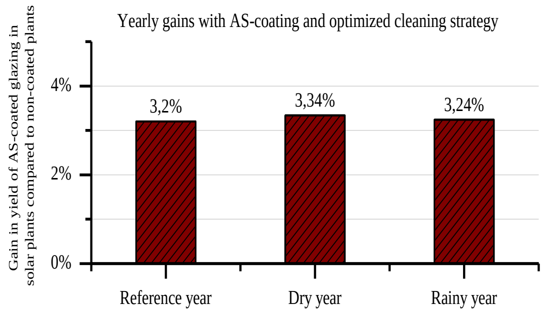

Figure 3: Yearly gain of yield by using anti-soiling coatings in addition to the optimal, mechanical cleaning procedure in three different climatic scenarios

The economic benefit by extending the times between the necessary cleaning steps and by keeping the transmission up for a longer time or by avoiding a fast clogging of the PV module surfaces trough dust accumulation is shown. The necessary frequency of cleaning procedures depend strongly on the local conditions and can be far above 10 times per year. Since we assumed 10 cleaning procedures per year, the benefits for anti-soiling coatings would be even higher.

4.2 Efficiency of artificial dusting

The transmittance spectra of the samples of the coated PV module glazing materials were determined initially and during the soiling tests. In order to evaluate the dirt-repellent properties, the transmittance was observed via FTIR/UV-Vis spectroscopy and compared to the transmittance of uncoated glass substrates. The dew test compared to the dry dust test shows less loose dust and less visual transmittance.

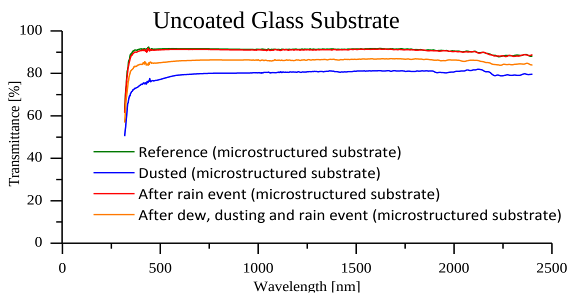

Figure 4: Spectral transmittance of uncoated glass substrates after soiling tests and artificial rain.

The non-coated glass showed a transmittance loss due to dust of 11.3 percentage points after the soiling tests (Fig. 2, blue graph). After the simulated rain event the transmittance is restored to its initial value (green and red graph). The loose dust is easier to be removed by the water. The dew and soiling test with the dried soil, pointed out that the (artificial) rain is not strong enough to clean the surface and not strong enough to restore the transmittance to its initial value. A transmittance loss of 5% is measured after just one test cycle with dried dust and once artificial precipitation (orange graph).

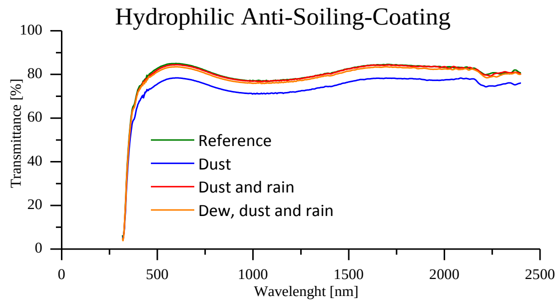

Figure 5: Spectral graphs of anti-soiling coated glass substrates after soiling tests and artificial rain.

Compared to the uncoated glass substrate, the transmittance of anti-soiling coated samples recovers easier by cleaning by artificial rain simulation, even after moist-soil-mixtures (see Table II).

Table II: Measured solar transmittance indicating the efficiency of the tested anti-soiling coating

	Soil (dry)	**Soil (dry) + Irrigation**	**Dew-Soil + Irrigation**
Solar Transmittance	ΔT [%]	ΔT [%]	ΔT [%]
Uncoated substrate	- 11,3	- 0,3	- 5,2
AS-Coated sample	- 6	- 0,3	- 1,17

5 CONCLUSION

5.1 Coating market and economic feasibility

Available anti-soiling coatings can be mainly divided into three groups according to their type of functionality: hydrophobic, hydrophilic and hydrophilic/photocatalytic. The economic feasibility study uses modeling to investigate the benefit of cleaning in arid regions and shows that coating can help to reduce the cleaning effort and the water consumption drastically, which can affect the yearly energy yield positively by approximately 3% .

5.2 Soiling test

During the soiling tests, the transmittance values were significantly reduced. Generally uncoated patterned glass shows higher losses in transmittance than smooth surfaces of float glass substrates. After one round of the dry soiling test as well dew soiling simulation is already a marginal reduced transmittance in both, the uncoated glass substrate and the anti-soiling coating, detectable. Although the anti-soiling coating showed a tendency to easier cleanability and it’s transmittance values are recovering to almost initial values, even after the dew soiling test. However, there is an increasing demand for durable anti-soiling coatings by the solar industry, because they are expected to reduce the need for frequent cleaning. Monitoring the long term stability with accelerated ageing tests is still to be performed.

6 REFERENCES

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