ANALYSIS OF PERFORMANCE ENHANCEMENT OF PV SYSTEMS AFTER A CLEANING EVENT

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ABSTRACT: Airborne dust accumulation or soiling phenomenon is one of the challenging issues that negatively affects the spectral transmittance and thus the energy yield of solar PV systems. Hence, cleaning can be necessary to ensure the performance of a PV module and its lifetime. The overall goal of this study is to propose a cleaning success index and to investigate the impact of cleaning events on the energy yield of a real PV plant in Bern University of Applied Sciences (BFH) in Burgdorf, Switzerland. The monitoring of the PV systems operates under cleaning cycle of once in 4 years since the region is characterized by a warm-temperate climate with an average annual temperature of 10.7 °C, and the rainfall is significant with an average annual precipitation of 1005.7 mm+/-13%. In this study, MATLAB software is used to pre-process and analyze ten years of recorded data. As known, PV module retrieves its performance after a cleaning event, then after a variable period, the performance decreases again. A methodology to evaluate the cleaning success is proposed and evaluated. For this purpose, the performance ratio (PR) is used to determine a cleaning success index. The latter indicates an average of 6 % after one month of cleaning and 2 % after one year of all cleaning events.

Keywords: Cleaning event, Performance ratio, cleaning success

1 INTRODUCTION

A well-planned cleaning cycle for solar PV installations is a critical issue as it has impacts on long-term degradation and energy loss [1]. Many cleaning companies advertise for high additional energy yield when modules are cleaned. However, there is no standard way how to evaluate cleaning success. Several publications on the benefit of cleaning and the optimization of cleaning have been published. D. L. Alvarez et al. [2] proposed an approach to select the optimal cleaning schedule based on different factors, such as soiling, cleaning and energy costs. Irradiance profile and analytic explanation are used to estimate this strategy. Micheli et al. [3] analyzed the impact of nonuniform soiling on the power of PV system for 3 years. It was found that 8 % of the annual DC energy was reduced by soiling. For the cleaning strategy, three cleaning events per year was the best choice for the economic conditions. K. A. Moharram et al. [4] investigated the influence of a cleaning methodology on the PV plant efficiency. The proposed strategy was based on the use of water only, non-pressurized water system and a surfactant. From the results of these experiments, it was found that cleaning by water and non-pressurized water lead to a decrease in the PV panel efficiency by 50 % after 45 days, and 0.14 % per day, respectively. While using a mixture of anionic and cationic surfactants was the best cleaning method.

Cleaning of PV system shall retrieve the system efficiency. A frequent cleaning using demineralized water is a powerful solution to keep the soiling impact low. However, the needed water presents another issue since there is a lack and decline in resources especially in countries with a high solar potential. In Switzerland, cleaning is expensive due to high labor cost and low energy prizes. Recently, Cattani, L et al. [5] proposed air to water generator (AWG) technology as the suitable solution for cleaning PV modules. For their case, a method and semiempirical model were used to determine the system size and the energy loss, respectively. From the found results, the applied AWG model could prohibit 83% of energy loss caused by the soiling. Amber, K. P., et al. [6] developed an automatic self-cleaning mechanism (SCM) for a pole mounted PV installation. Daily performance of two exposed PV panels was recorded for a period of 6 weeks, one PV was left as reference and the other with SCM. For the latter, it could produce 26% to 50% of electricity more than a panel without SCM, and reduction of 86 % in the efficiency was observed for the reference panel after the experimental period. Hiroutochi [7] proposed Molecular-bond-Titania-Silica-Photocatalyst as a self-cleaning of PV modules to maintain its performance. It was mentioned that this method was effective since it improved the transmittance of the PV modules, hence the power generation.

A. Syafiq et al [8] reviewed the different developed and proposed self-cleaning methods, namely electrostatic, mechanical, and coating methods. S. You et al. [9] investigated the energetic and economic impacts of soiling on PV modules in different cities, as well as the determination of the optimal cleaning intervals based on the simulation of the relative net present change. For the manual cleaning, the optimal predicted interval ranges found to be from 23 to 70 days, while for machine-assisted cleaning method was 17 to 49 days. The optimal cleaning intervals vary according to the studied cities for both cleaning methods. L. Micheli, E.F. Fernandez, J.T. Aguilera et al. [10] discussed the adopted cleaning strategy for 1 MW PV system in the South of Spain. For moderate climate, seasonal soiling occurs and could lead to power drops up to 20 %. In their study, one cleaning event per year was done during an approximately 31-day window in summer. This cleaning schedule could increase the profits up to 3.6 %, and it has positive impact on the module efficiency. Obeidat, M. S et al. [11] presented and compared different cleaning methods, namely electrostatic cleaning, heliotex technology, automatic cleaning, self-cleaning glass and manual cleaning. Using the preference selection index analysis, it was found that the manual cleaning is the best cleaning method.

Most of studies discussed above claim to achieve a certain cleaning success. However, they do not always clearly define how they measure the cleaning success. Nor do they discuss if their way to measure cleaning success is the best possible option.

The main purpose of the present investigation was to propose and analyze a method to evaluate the cleaning success. A set of indicators and metrics are explored to reach the purpose of this study. To do so, MATLAB software is used to analyze the data and calculate the proposed metrics using their standard equations. Indeed, as a performance metric, the performance ratio (PR) was used, which presents the level of the PV plant performance. To evaluate the cleaning success, the ratio of the PR before and after a cleaning event is used.

2 PV SYSTEM AND CLEANING METHODOLOGY

In this study, the cleaning of Tiergarten PV system is analyzed. This system is mounted on the rooftop of Bern University of Applied Sciences (BFH) in Burgdorf city, and it is divided into two sub-systems, namely Tiergarten West and Tiergarten East. The total nominal DC power of the PV system is 46 kW with a gross area of 350 m^2. The proposed and adopted cleaning frequency of both systems is four years. Table 1 presents the proposed cleaning strategy, and some occurred exceptions. Seven cleaning events were done for Tiergarten West, while Tiergarten East benefited from six cleaning events (no cleaning C4).

Table 1. Cleaning strategy of studied PV systems

Cleaning event	Year	
	Tiergarten West	Tiergarten East
C1	1998	1998
C2	2002	2002
C3	2006	2006
C4	2010	--
C5	2012	2012
C6	2016	2016
C7	2020	2020

3 PERFORMANCE INDICATORS

In this study, the performance of the investigated systems is presented by the performance ratio (PR), and it is calculated using the following ratio:

$$PR=\frac{Y_{DC\text{-}corr}}{Y_r} \qquad \text{(Equ.1)}$$

Where, $Y_{DC\text{-}corr}$ and Y_r are the corrected DC yield and the reference yield, respectively.

The reference yield is the ratio of the total tilted solar irradiance (GTI) to the refence solar irradiance (G_{STC}) [12]. In this study case, GTI is filtered, and only values between 700 W/m^2 and 900 W/m^2 are used for the calculations. Y_r is presented as:

$$Y_r = \frac{G_{gen}}{G_{STC}} \qquad \text{(Equ.2)}$$

The corrected DC yield is defined by the expression:

$$Y_{DC\text{-}corr}= \frac{E_{DC}}{P_{nom}} \times k_T \qquad \text{(Equ.3)}$$

Where, E_{DC} is the total DC energy output produced by the system and P_{nom} is the nominal power of the PV system at STC. k_T denotes the temperature correction factor and it is expressed as:

$$k_T = 1+\alpha_{Pmpp}\times(T_{ref}-25) \qquad \text{(Equ.4)}$$

Where α_{Pmpp} is the temperature coefficient (%/°C) and T_{ref} is the solar generator cell temperature.

To determine the effect of cleaning on the performance of PV systems, a cleaning success index (C_s) is defined and calculated according to the PR before (PR_b) and after (PR_a) the cleaning for different time intervals. C_s can be expressed as follows:

$$C_s=\frac{PR_a-PR_b}{PR_b} \qquad \text{(Equ.5)}$$

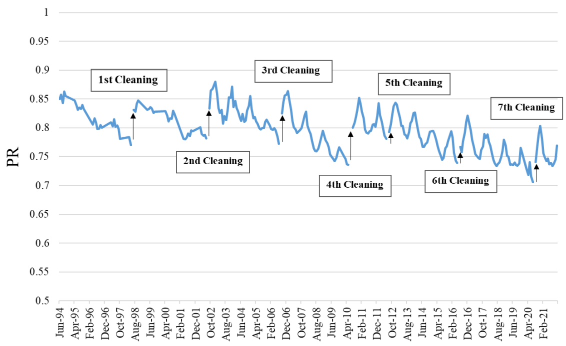
The PR_a and PR_b are calculated by adding up the ratio between the corrected yield and the reference yield before and after cleaning:

$$PR_a = \frac{\sum_{d=1}^{N} Y_{DC-corr,d}}{\sum_{d=1}^{N} Y_{r,d}} \qquad \text{(Equ.6)}$$

$$PR_b=\frac{\sum_{d=-1}^{-N} Y_{DC\text{-}corr,d}}{\sum_{d=-1}^{-N} Y_{r,d}} \qquad \text{(Equ.7)}$$

Where d is the number of days after cleaning (negative d and is the number of days before cleaning) and N is the total number of days used to analyze the cleaning success. The cleaning success index (C_s) is intended to show how sustainable an individual cleaning action is.

4 RESULTS



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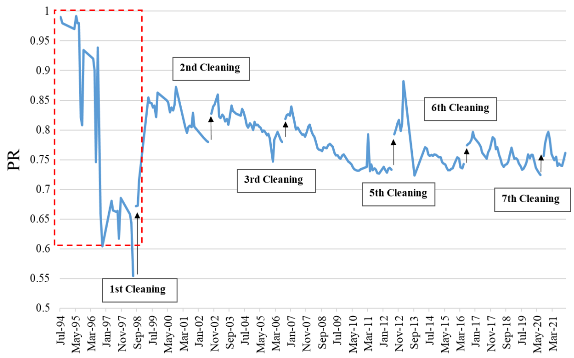

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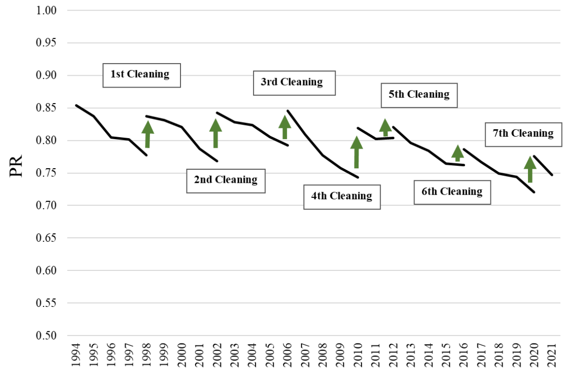
Figure 1. Cleaning events according to monthly PR for Tiergarten West (a) and Tiergarten East (b)

Figure 1 and Figure 2 show the monthly and annual performance of the PV systems for 25 years considering the data of the whole year, respectively. For Tiergarten West (Figures 1a and 2a), seven cleaning events were done, while for Tiergarten East (Figures 1b and 2b), 4th cleaning is missed. It should be noted that the plot part which is surrounded by the red dash rectangle contents unverified and non-plausible data. As shown in both graphs, two PR values are plotted for each cleaning event that present the PR of the system before and after the cleaning. The seasonal variation of the PR is based on the definition of the PR in this paper which does not account for IAM, low irradiance efficiency and other performance loss factors of a PV system.



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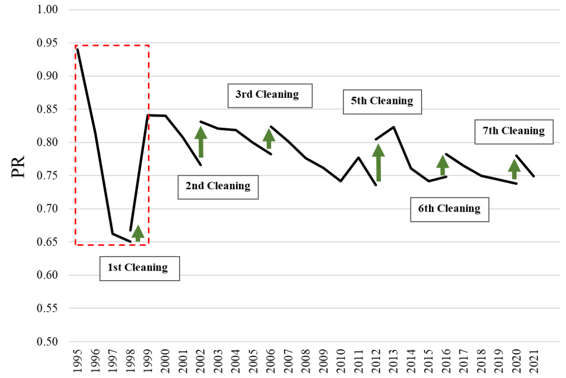

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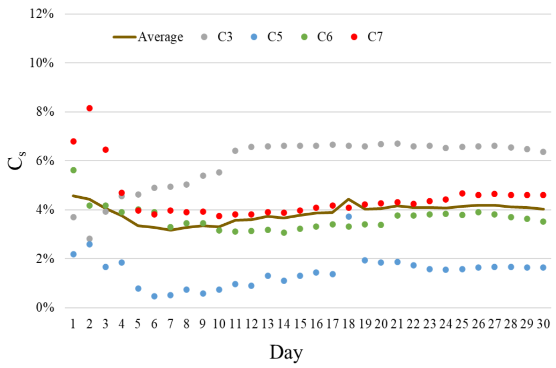
Figure 2. Cleaning events according to annual PR for Tiergarten West (a) and Tiergarten East (b)



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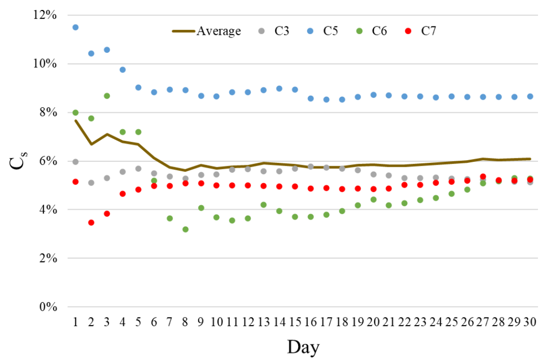
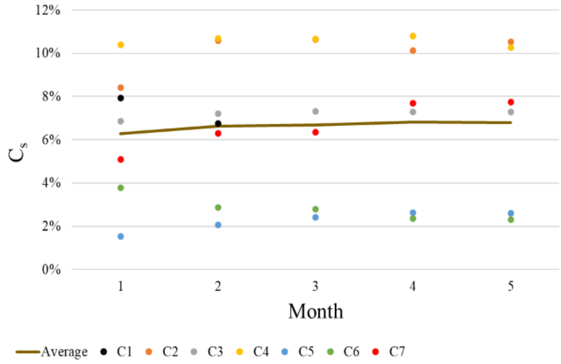


(b)

Figure 3. Cleaning success according to number of days after and before cleaning event for Tiergarten West (a) and Tiergarten East (b)

Different step times were analyzed to identify the impact of cleaning events on the performance of the PV systems. Figure 3 presents the C_s as function of the number of days after each cleaning event. As observed, some cleaning events are missed in both graphs because only monthly details of the cleaning date are available. The solid line indicates the average C_s of all plotted cleaning events, and it shows the trend the C_s over the next 30 days.

Figure 4 presents the monthly impact of cleaning on the performance of PV system up to five months after each cleaning event. All cleaning events are included in the graphs. For C1, only the results up two months after this cleaning are available for Tiergarten systems. While the cleaning success decreases quickly only after a few days (Figure 3), it seems to rise again after a few months (Figure 4). However, this is probably based on the seasonal PR rise in winter, as the same increase of performance can be seen in years without cleaning.



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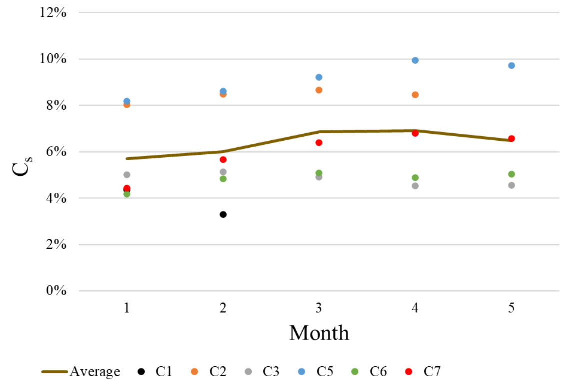


(b)

Figure 4. Cleaning success according to number of months after and before cleaning event for Tiergarten West (a) and Tiergarten East (b)

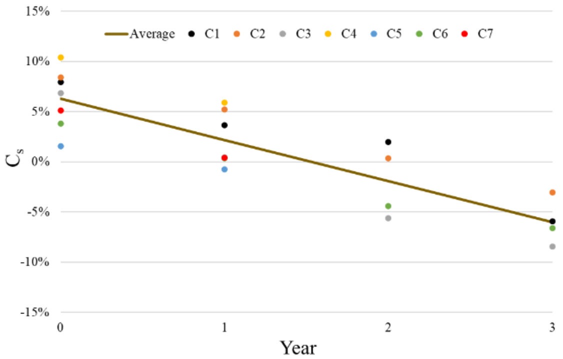
Table 2 presents the impact of the cleaning events on the PR after one month. As indicated, C_s varies for each cleaning event and the highest C_s was 10 % and 8 % for Tiergarten West and Tiergarten East, respectively.

Table 2. Cleaning success after one month of cleaning event

Cleaning event	C_s (%) after the 1st month	
	Tiergarten West	Tiergarten East
C1	8	4.5
C2	8	8
C3	7	5
C4	10	--

C5	2	8
C6	4	4
C7	5	4.5

Results of C_s up to three years after each cleaning event is shown in Figure 5. Notable decrease in the C_s over the next years is presented. Overall, the negative C_s indicates that the cleaning event had no more efficient impact on the Tiergarten system, and the latter retrieved its performance when the next cleaning is occurred.



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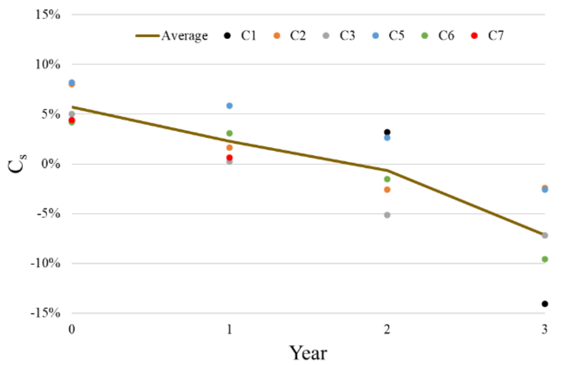

(b)

Figure 5. Cleaning success according to number of years after and before cleaning event for Tiergarten West (a) and Tiergarten East (b)

The daily cleaning evaluation curve (Figure 3) shows a rapidly decreasing cleaning success curve. If cleaning success is measured on a power-based performance ratio directly before and after cleaning, the relevant cleaning success is therefore most likely overestimated. The monthly evaluation (Figure 4) shows an increasing cleaning success, which is based on inaccurate PR models and therefore most probably biased. Monthly cleaning success should therefore only be used, if the reference power of the PV system is well understood and modeled, unlike in this paper. The annual cleaning success curve (Figure 5) is most relevant if the optimization of long-term revenues is the target of the cleaning success metrics.

5 CONCLUSION

In the present study, cleaning strategy of Tiergarten PV system is investigated. This system is in Bern University of Applied Sciences (BFH) in Burgdorf, Switzerland and it is divided into two sub-systems, namely Tiergarten West and Tiergarten East. The monitoring of the PV systems occurs under cleaning frequency of once in 4 years. Proposed methodology to analyze the cleaning success of cleaning on the performance of the PV systems for different step times. Thus, the performance ratio is used to calculate the cleaning success index (C_s) which indicates the increase in the performance of the PV systems after each cleaning event.

Based on found results, for Tiergarten West, the C_s is between 2 % and 10 % after one month of cleaning and between 4 % and 8 % for Tiergarten East. After one year of the different cleaning events, C_s ranged from -1 % to 6 % and from 0 % to 6% for Tiergarten West and Tiergarten East, respectively. However, the evaluation of the cleaning success of a PV system depends on PR model used and the analyzed step time.

6 REFERENCES

[1] S. Warade, A. Kottantharayil, and Ieee, "Analysis of Soiling Losses for Different Cleaning Cycles," in *7th IEEE World Conference on Photovoltaic Energy Conversion (WCPEC) / A Joint Conference of 45th IEEE PVSC / 28th PVSEC / 34th EU PVSEC*, Waikoloa, HI, Jun 10-15 2018, in World Conference on Photovoltaic Energy Conversion WCPEC, 2018, pp. 3644-3647. [Online]. Available: <Go to ISI>://WOS:000469200403156

[2] D. L. Alvarez, A. S. Al-Sumaiti, and S. R. Rivera, "Estimation of an Optimal PV Panel Cleaning Strategy Based on Both Annual Radiation Profile and Module Degradation," *Ieee Access,* vol. 8, pp. 63832-63839, 2020, doi: 10.1109/access.2020.2983322.

[3] L. Micheli, E. F. Fernandez, A. Fernandez-Solas, J. G. Bessa, and F. Almonacid, "Analysis and mitigation of nonuniform soiling distribution on utility-scale photovoltaic systems," *Progress in Photovoltaics,* vol. 30, no. 3, pp. 211-228, Mar 2022, doi: 10.1002/pip.3477.

[4] K. A. Moharram, M. S. Abd-Elhady, H. A. Kandil, and H. El-Sherif, "Influence of cleaning using water and surfactants on the performance of photovoltaic panels," *Energy Conversion and Management,* vol. 68, pp. 266-272, Apr 2013, doi: 10.1016/j.enconman.2013.01.022.

[5] L. Cattani, P. Cattani, and A. Magrini, "Photovoltaic Cleaning Optimization: A Simplified Theoretical Approach for Air to Water Generator (AWG) System Employment," *Energies,* vol. 14, no. 14, Jul 2021, Art no. 4271, doi: 10.3390/en14144271.

[6] K. P. Amber, I. Hussain, A. Kousar, M. A. Bashir, M. W. Aslam, and B. Akbar, "A SELF-CLEANING DEVICE FOR POLE MOUNTED SOLAR PHOTOVOLTAIC INSTALLATIONS," *Thermal Science,* vol. 23, no. 2, pp. 739-749, 2019, doi: 10.2298/tsci170401065a.

[7] H. Nakagawa, K. Mathuoka, H. Yonemori, and Ieee, "A Study about the Self-Cleaning of a PV Module Surface Using Photocatalyst," in *2nd IEEE Region10 Humanitarian Technology Conference (R10 HTC)*, Chennai, INDIA, Aug 06-09 2014, in IEEE Region 10 Humanitarian Technology Conference, 2014, pp. 82-87. [Online]. Available: <Go to ISI>://WOS:000410630400016

[8] A. Syafiq, A. K. Pandey, N. N. Adzman, and N. Abd Rahim, "Advances in approaches and methods for self-cleaning of solar photovoltaic panels," *Solar Energy,* vol. 162, pp. 597-619, Mar 2018, doi: 10.1016/j.solener.2017.12.023.

[9] S. M. You, Y. J. Lim, Y. J. Dai, and C. H. Wang, "On the temporal modelling of solar photovoltaic soiling:

Energy and economic impacts in seven cities," *Applied Energy,* vol. 228, pp. 1136-1146, Oct 2018, doi: 10.1016/j.apenergy.2018.07.020.

[10] L. Micheli, E. F. Fernandez, J. T. Aguilera, and F. Almonacid, "Economics of seasonal photovoltaic soiling and cleaning optimization scenarios," *Energy,* vol. 215, Jan 2021, Art no. 119018, doi: 10.1016/j.energy.2020.119018.

[11] M. S. Obeidat, E. M. A. Alhalim, and B. R. Melhim, "Systematic Approach for Selecting a Cleaning Method to Solar Panels Based on the Preference Selection Index Approach," *Jordan Journal of Mechanical and Industrial Engineering,* vol. 14, no. 3, pp. 279-287, Sep 2020.

[12] IEC61724-1:2017, *Photovoltaic System Performance—Part 1: Monitoring*. International Electrotechnical Commission:Geneva, Switzerland, 2017