EVAPORATING PURE RAINWATER TO INCREASE THE YIELD OF COMMERCIAL-SIZE PV ARRAYS

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ABSTRACT: This paper summarizes 5 years of R&D efforts towards for the conception of PV module cooling equipment that would be economically sound for retrofitting existing PV plants in temperate and tropical climates. It is well established that cooling Si-based PV modules does increase their power output by ~0.45%/°K. The initial objective of the research was to identify the most effective method to cool large arrays of modules: the outcome was to maximize the evaporation of droplets of pure rainwater entering into contact with the solar glass surface. The next objective was to devise a method that would optimize use of the water resources, (i.e. of rainwater collected in the winter) and maximize the overall power output gains across the year. This resulted in connected equipment driven by industrial algorithms, which continuously calculate 2 main factors: the "cooling opportunity" and the "cooling cost", thereby ensuring at any instant the financial viability of cooling the PV modules. The paper shows the relationship between solar irradiation and power output and detailed comparative results obtained from the all-year-long cooling of existing commercial-size PV plants in Europe.
Keywords: Water Cooling, Silicon modules, Photovoltaic Panels

1 INTRODUCTION

The performance of a PV system depends on several parameters and there are numerous issues that can reduce the expected efficiency of commercial PV plants; among them, one is high operational cell temperature and another is the dirt and dust particles accumulated on the front surface of the PV panel. It is well known that operational temperature can decrease the performance by up to 18%-29% compared to panels held at standard test temperature [1-3], whereas dust loss can amount to 30%.

The heat issue has been thoroughly researched and different cooling strategies have been developed to reduce module temperature and increase efficiency [4-8], although water cooling has clearly proved to be one of the most effective techniques [9,10]. In spite of the many systems proposed for water-based cooling, none of them demonstrated economic feasibility.

In this paper we present a summary of 5 years of R&D efforts towards for the conception of PV module cooling equipment that is economically sound for retrofitting existing PV plants in temperate and tropical climates [11,12].

Company SUNiBRAIN of France developed a commercial system that cools, cleans and performs a monitoring of the PV modules, optimizing the resources used. The initial objective of the research was to identify the most effective method to cool large arrays of modules: the outcome was to maximize the evaporation of droplets of pure rainwater entering into contact with solar glass surface [13]. The next objective was to devise a method that would optimize use of the water resources, (i.e. rainwater collected in the winter) and maximize power output gains across the entire year.

2 SYSTEM DESCRIPTION

The performance validation was based on the use of a twin solar system (specially built as real-size test equipment offering the possibility of real-time comparison) during periods of autonomous production and operation of the cooling/cleaning system without human intervention. The first complete calendar year of fully autonomous operation was 2013.

The installation consists of a steel roof with mounting systems and PV modules with two absolutely identical solar generators of which one only is equipped with the cooling/cleaning system. In order to prevent temperature contagion between the two generators, they are separated by a buffer zone (Fig. 1 top).

Figure 1: (Top) Test System consisting in 2 twin generators separated by a buffer zone. (Bottom) Thermographic image of the roof showing the cooling effect by the SUNiBRAIN system.

Each solar generator is instrumented with various measurement instruments (separate electric meters, multiple sensors for t°, wetting, irradiance, weather parameters, etc.) to allow various analyses including:

- Continuous monitoring of production gains
- Analysis of t ° and PR curves
- Daily study of strings current and voltage as a function of t° differentials
- Frequency distribution of operating powers over time

- Calculation of production gains and of changes in the performance ratio

This system is driven by industrial algorithms, which continuously calculate 2 main factors: the “cooling opportunity” and the “cooling cost”, thereby ensuring the financial viability of cooling PV modules at any instant (Fig. 2).

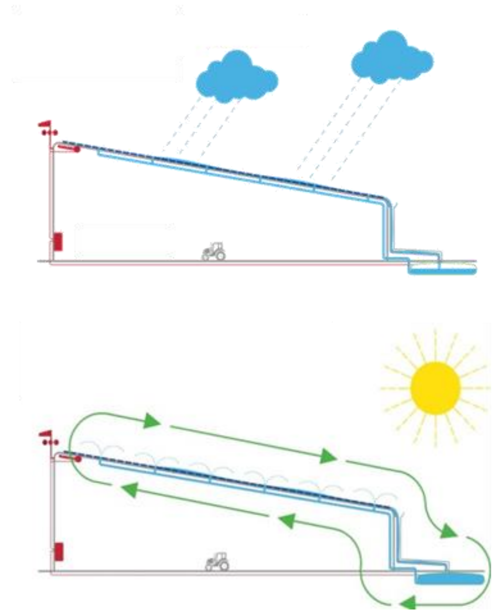

Figure 2: Function diagram of the system developed to cool and clean on-roof PV installations.

3 RESULTS

3.1 Performance

In Figure 3, each bar represents the kWh hourly output of the inverters of twin PV installations over a day: SUNiBRAIN-equipped generator in blue, reference generator in red.

The difference between the red and the blue bars represents the output differential of the two inverters, i.e. the SUNiBRAIN gain.

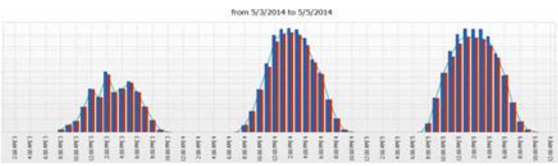

Figure 3: SunnyPortal, SMA datalogging

Figure 4 shows the relationship between solar irradiation and power output. The power output gain (red curve, right scale) and the temperature drop (blue curve, left scale) obtained from real-time comparison of the modules of each of the twin solar generators is presented. The power output differential (red) is not a perfect inverse of the t° differential (blue), but it is close. This very strong correlation demonstrates how the SUNiBRAIN system is capable of anticipating the cooling opportunities, i.e. the moments when it is economically useful to cool the solar field.

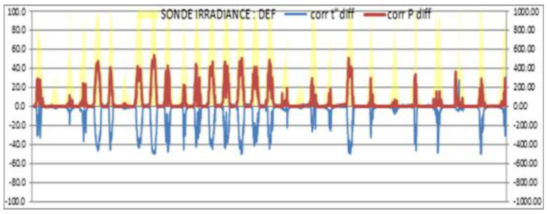

Figure 4: 30-days of t° differential (blue, in °K, left axis), power differential (red, in %, left axis) and solar irradiation (yellow, right axis)

The monthly performance gains shown (Fig.5) represents the differential output of the two PV fields, namely:

$$Gain(\%) = \frac{\left(PowerOutput_{SIBGenerator} - PowerOutput_{ref.Generator}\right)}{PowerOutput_{ref.Generator}}$$

The monthly distribution of gains varies quite widely from one year to another, depending on monthly weather conditions (wind, precipitations and cloud cover). However, the total annual gain is statistically much more stable from one year to another.

The total power output differential in 2013 – i.e. the average annual gain – was 6.24%

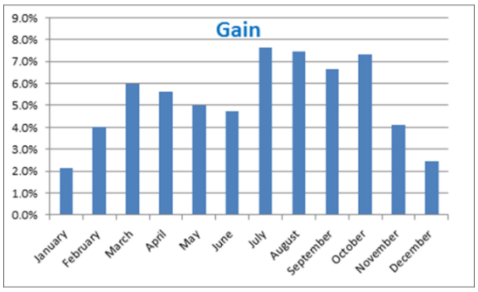

Figure 5: Monthly performance: Power output gain from cooling the panels.

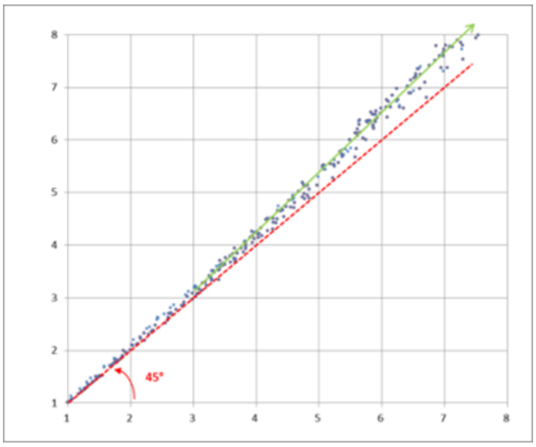

Figure 6: Full-year comparison of daily power output (in kWh) from non-cooled (H axis) vs. cooled- PV (V axis).

Graph in Figure 6 shows the power output over a full day of production. The position of each dot depends on the total daily output of the reference generator (X) and total daily output of the generator equipped with SUNiBRAIN (Y). Each dot above the red line represents a day when the SUNiBRAIN generator produced more output than the reference generator. Dots on the 45% line correspond to days when the SUNiBRAIN cooling system is not working at all (e.g. freezing conditions, excessive wind, rain, etc..) This happens especially in the bottom of the graph, i.e. by days of rather weak sunshine.

3.2 Predictability of performance and PR validation

Whenver data is available to compute or assess the frequency distribution of the power output of a solar generator (on the above graph the blue bars, left scale) and expressed for each percentile group of power output (here on the x-axis, expressed as a %age of the inverters nameplate capacity), and knowing the efficiency of the inverter at each power level, as well as the average gain generated by SUNiBRAIN at each power level (green curve, left scale), it is possible to interpolate correctly, in terms of volume and frequency, the gains for each power level (blue curve, right scale). Using integral calculus, this blue curve provides an estimate the average gains of equipping an existing PV generator with SUNiBRAIN.

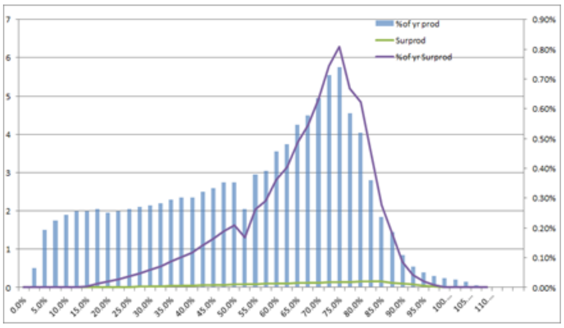

Figure 7: Estimating output gains using the frequency distribution method. Interpolation based on statistical data obtained from inverter manufacturer SMA, Inc. for a solar generator near the French city of Colmar.

In a similar way, whenver irradiance data is available, simple methods make it possible to validate, in terms of performance ratio, the benefits from installing SUNiBRAIN on a PV generator.

5 CONCLUSIONS

The cooling system is able to accumulate power generation gains not only in summer, but under very many meteorological conditions throughout the year.
Several years of developments allowed us to improve our models of the cooling mechanism of solar arrays.

The key progress factors were the integration of factors, such as such as hygrometry and air density, which influence the rate of water evaporation. Beyond instrumentation, the cooling equipment's firmware was reprogrammed to make better use of such environmental data, and to derive in real time more realistic financial estimates of the "cooling opportunity" and the "cooling cost", thereby ensuring at any instant the financial viability of using spending rainwater to cool the PV modules. The result is industrial equipment (incl. rainwater recycling and storage) whose cost can be amortized over a period of only a few years even in central European climates.

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