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VIRTUAL LABORATORY FOR TESTING OF SOLAR POWER PLANTS IN BIG DATA ANALYSIS

R.M. Asimov[1],
PhD, CEO of Sensotronica Ltd

S.V. Valevich[3],
Graduate student BSUIR

I. Kruse[2],
CEO of SunSniffer GmbH

V.S. Asipovich[3],
PhD, associate professor BSUIR

[1]*Sensotronica Ltd, Kulman, 9, 373, Minsk, 220010, Republic of Belarus. E-mail: roustam.asimov@sensotronica.com*
[2]*SunSniffer GmbH & Co. KG, Ludwig-Feuerbach-Str. 69, Nuremberg 90489, Germany. E-mail: ingmar.kruse@sunsniffer.de*
[3]*Belarussian State University of Informatics and Radioelectronics, P. Brovki, 6, Minsk, 220013, Republic of Belarus. E-mail: v.osipovich@bsuir.by*

R.M. Asimov

In 1990 graduated from Tajik National University, faculty of Physics. He conducted research in the Institute of Physics of the National Academy of Sciences of Belarus and in Paris-Nord University (France). In 2012 he got his PhD with a thesis on laser-induced photodissociation of hemoglobin complexes. He is the author of 134 publications and 7 teaching aids, also he holds 14 patents. Currently he is CEO of Sensotronica (resident of Belarusian High Technologies Park). Main areas of research activity: development of algorithms and technologies for Big Data processing, research and math modeling of photophysical processes.

S.V. Valevich

In 2017 graduated from the BSUIR with degree in Engineering. In 2018 got Master's degree in Engineering.

I. Kruse

Since the early 80s he develops innovative technology. In 1983, a year before his graduation, he founded his first company. He studied Business Administration in Nuremberg and Computer Science in Atlanta, USA. In 1996 he received a rare license from Apple for the production of Apple computers. Since 2002 he is in photovoltaic industry. He holds several patents in different fields.

V.S. Asipovich

In 2004, he graduated from the Belarusian State University of Informatics and Radioelectronics with a degree in Microelectronics, and in 2005, he got a master's degree in the same specialty. In 2010, he defended the thesis for the degree of a candidate of technical sciences in Devices, systems and medical items. He is the author of 115 publi-

cations, 2 patents, 12 teaching aids. Annually he orally reports at international scientific forums. Main areas of research activity: development of algorithms and technologies for big data processing, research and development in the software processing of medical images.

Abstract. A virtual laboratory for Flash-tests of solar panels under standard field conditions has been proposed, implemented and tested. The results of testing showed the following. DT is able to provide STC data from field measurements. Forecasts can be done on real performance values. Virtual Flasher produces results that correlate better to the behavior of the module in the field.

Keywords: Digital twin, Virtual lab, Photovoltaic, Flash-test, Analytics engine, Flash-tests.

Introduction

Solar energy currently consists of power plants that have a total capacity of more than 500 GW. The projected increase in 2019 will be about 120 GW. It is a rapidly growing power generation industry that requires constant monitoring and maintenance. However, modern monitoring technologies [1] have limitations. The main disadvantages are: 1) the inability to search for a faulty panel and determine the type of its malfunction; 2) the lack of removal of the current-voltage characteristics of the panels at the place of installation "in the field"; 3) there is no forecasting of production, taking into account weather conditions. At the same time, the amount of information on the situation of power plants is constantly growing. When all values polled at 5-minute intervals, just for all solar plants in the same time it will generate about 40 Tbyte information daily.

A lot of various parameters affect PV panel's contamination level. Soiling is quite important factor and may vary depending on the region and climate. This factor consists of various parameters which could be combined into 3 categories: environment factors (weather, temperature, irradiation, rain, snow, etc.), dust composition and location of panel together with panel's installation properties. Classification of these factors was studied in Malaysia [2]. Dust reduces panel's performance mostly based on dust type and accumulated dust weight on cell's surface [3]. Environment factors and panel specifics could be studied together on real solar plants. It's possible to study power losses using two solar cells which are located near each other and one of these cells is washed regularly while the second stays dirty [4]. Soiling effect on real PV panels should be studied in order to create some mathematical model which would estimate power losses from soiling based on time and data from sensors.

The aim of the work is to develop the Digital Twin concept proposed by the authors [5] in terms of removing the current-voltage characteristics of solar panels "in the field" (conducting flash tests without using specialized laboratories) and analyzing the level of contamination of solar panels. One of the sub-goals is to conduct in-depth analysis of soiling effect.

Results

The solution to this problem of removing the current-voltage characteristics "in the field" can be a virtual measurement laboratory to assess the effectiveness and type of malfunction of solar panels. Such a laboratory (Virtual Flasher) was implemented using a digital twin of a solar panel based on its mathematical model [2]. A block diagram of the measurement using Virtual Flasher is shown in Figure 1.

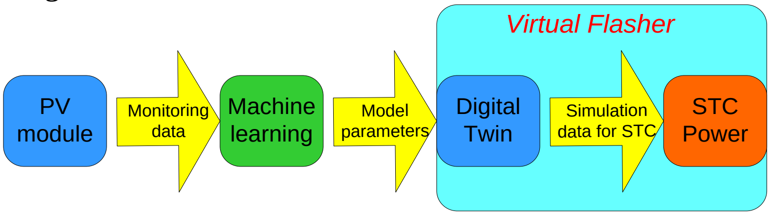

Figure 1. The scheme of conducting Flash-tests in a virtual laboratory

To search for faulty solar modules at a power plant consisting of more than 500 panels, infrared cameras were used. We mounted on top of the telescope stick and filmed the whole plant using IR camera Optris PI 450 (Optris Infrared Sensing, USA). The second one was the high-resolution handheld camera we used to make some additional pictures of interesting modules, it's called Variocam HD 640 (InfraTec, Germany). This is the other IR camera used in the filed to look closely into the interesting modules and for to measure temperature of modules.

*The defective modules detected in this way were removed and delivered to the laboratory. Flash-tests were conducted in the laboratory under Standard Test Conditions (STC): current-voltage characteristics and power generated were measured at a panel temperature of 25 ° C and a solar radiation level of 1000 W/m^2. The sample dataset was collected from the monitoring equipment of a real solar powerplant. The powerplant was equipped with solar panels type: “STORM Solar modul M190” (Germany).

After the panels were installed at the power plant, calculations of the generated energy under standard conditions were carried out using digital twins of solar modules in different periods of time. The results of measurements and calculations are presented in table 1. Majority of the modules show a consistent 1% drop of STC Power between August and September conditions.

Monitoring data on Module 2.3_10 shows midday voltage drop about 1/3 compared to other modules, indicating activation of a bypass diode while heated (fig. 1). Monitoring data on Module 2.2_16 tells that it produces noticeably more power compared to other modules while Flash test results tell that they should be equal (fig. 3).

Table 1

Results of measurements and work of the virtual laboratory STC power of the modules

Module ID	**IR analysis**	**Flash Test STC Power (Watt)**	**Digital twin calculated STC Power (Watt)**		**STC Power difference**		
		17th Aug	19 - 26 Aug	24 - 30 Sept	DT.Aug-Flash	DT.Sept-Flash	DT.Sept-DT.Aug
2.3_10	**Shattered Glass**	**167,3**	**137,8**	**146,4**	**-18%**	**-13%**	**6%**
2.2_16	After repair el. contact	**186,9**	203,7	202,6	9%	8%	-1%
1.10_11	Hot Cell	187,4	186,9	185,4	0%	-1%	**-1%**
1.10_17	Hot Cell	187,2	187,8	185,9	0%	-1%	**-1%**
1.9_11	Hot Cell	182,4	184,0	181,8	1%	0%	**-1%**
1.9_17	Reference	184,7	182,9	181,4	-1%	-2%	**-1%**
1.8_10	Reference	187,3	187,6	185,8	0%	-1%	**-1%**
1.7_1	Shattered Glass	180,5	184,0	181,6	2%	1%	**-1%**

Data from April till October was studied in order to estimate soiling effect on PV cells. Efficiency of specific cell should depend on dust level which could be changed during significant precipitations.

For rainy days detection there was no additional filtering (all days should be presented and none of the potentially rainy days should be filtered). After rain or washing cell’s efficiency should increase and produce more power with the same level of irradiance. Light precipitation will result in short-term peak of power efficiency, washing will grant even better long-term results. For rainy days detection all raw parameters are combined into midrange values per day. Cell’s efficiency by current is calculated as ratio between current and solar irradiation.

Sequence of the following days with higher efficiency by current is counted for each day and then all days with sequence >15 could be considered rainy. Additional data from Weather History API is used for manual validation of results.

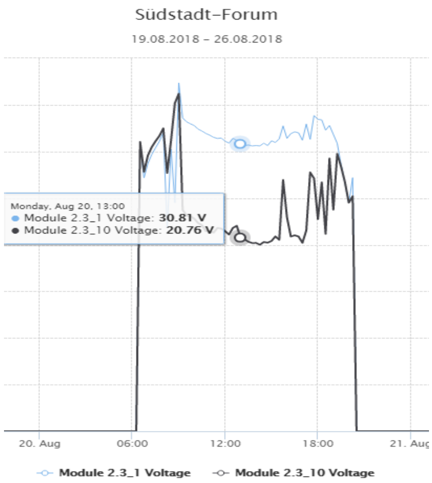

Figure 2. Voltage on Module 2.3_10 (black) and on Modul 2.3_1 (blue)

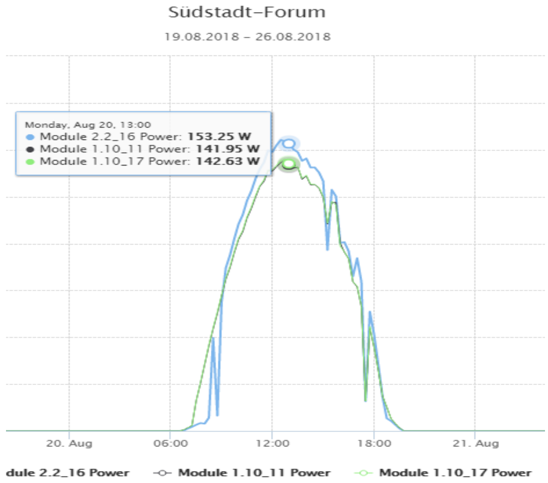

Figure 3. Power on Module 2.2_16 (blue) and on Modul 2.3_1 (green)

Another way of determining soiling effect includes knowledge and analysis of the days when the panels were washed.

Data points from two modules are filtered by irradiation (range between 875 and 925W/m^2), by temperature (range between 40 and 60C°) and via current lower limit (> 2A). These modules are located near each other and module 1.7_1 was washed on September 3rd while module 1.8_1 remained dirty. Previous washing happened before April.

Clean module shows similar to the second module's trend of efficiency measured by current/irradiation characteristic which is still higher for clean module (fig. 4) and positive trend of efficiency measured by power/irradiation (fig. 5).

Time series analysis of current and power efficiency (fig 4, 5) reveal the following:

1) Values of these parameters from panels 1.7_1 and 1.8_1 are almost identical before September 3rd. Values of current efficiency from panel 1.7_1 are slightly above the same values from panel 1.8_1 which may be related to insignificant difference between currents of string 7 and 8.

2) Tilt angle between current efficiency and X axis is greater for module 1.8_1 due to the fact that this parameter's value increased in average after September 3rd for module 1.7_1.

3) Trend lines of power efficiency for these modules show that power efficiency for module 1.8_1 decreased and, on the contrary, increased for module 1.7_1 during this time period.

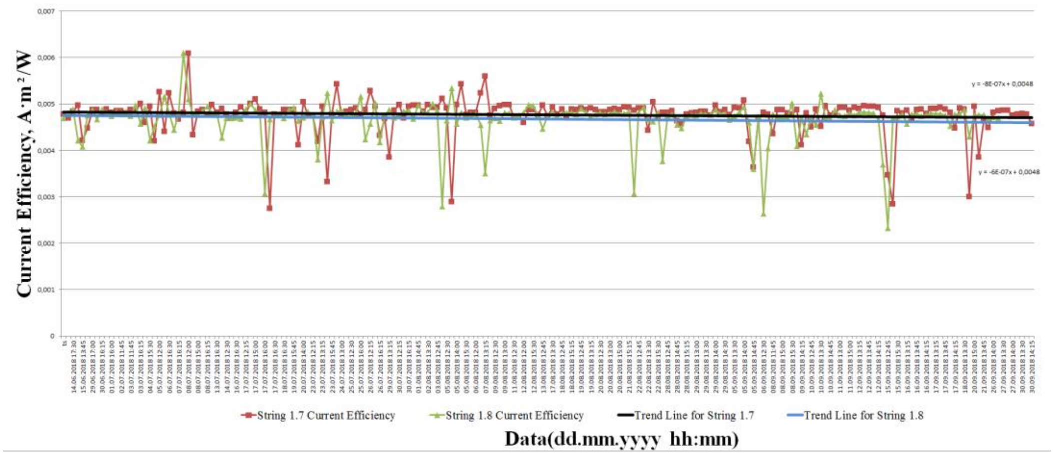

Figure 4. Efficiency and Trend lines by current for Modules 1.7_1 and 1.8_1

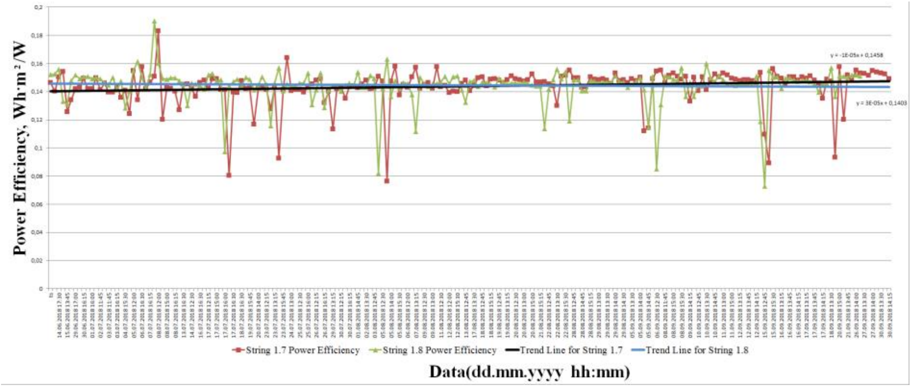

Figure 5. Efficiency and Trend lines by Power for Modules 1.7_1 and 1.8_1

Resume

Thus, the following conclusions can be drawn: virtual Flasher produces results that correlate better to the behavior of the module in the field; DT is able to provide STC data from field measurements; now forecasts can be done on real performance values; tilt angle of power efficiency's trend line indicates the degree of efficiency losses of the panel.

References

[1] List of monitoring and control systems for photovoltaic solar panels generators [Electronic resource] / – Mode of access: https://photovoltaic-software.com/monitoring-control-solar-PV-inverter-non-dependent-(multi-brand).php

[2] Maghami M., Hizam H., Gomes C., Radzi M., Rezadad M., Hajighorbani S. Power loss due to soiling on solar panel: A review. // Renewable and Sustainable Energy Reviews 59, 2016, pp. 1307–1316.

[3] Hussain A., Batra A., Pachauri R. An experimental study on effect of dust on power loss in solar photovoltaic module. // Renewables: Wind, Water, and Solar, 4:9, 2017.

[4] Gostein M., Caron R., Pachauri B. Measuring Soiling Losses at Utility-scale PV Power Plants. // Photovoltaic Specialist Conference (PVSC), 2014, IEEE 40th.

[5] Osipovich V.S., Asimov R.M., Chernoshey S.V. Digital twin in the Analysis of a Big Data // Collection of materials of the IV International Scientific and Practical Conference «BIG DATA and ADVANCED ANALYTICS», May 3–4, 2018, Minsk, BSUIR, pp. 69–78.

ВИРТУАЛЬНАЯ ЛАБОРАТОРИЯ ДЛЯ ТЕСТИРОВАНИЯ СОЛНЕЧНЫХ ЭЛЕКТРОСТАНЦИЙ В АНАЛИЗЕ БОЛЬШИХ ДАННЫХ

Р.М. Азимов
Кандидат технических наук, генеральный директор ООО "Сенсотроника"

С.В. Валевич
Магистрант БГУИР

И. Круз
Генеральный директор SunSniffer GmbH, Германия

В.С. Осипович
Доцент кафедры ИПиЭ, кандидат технических наук

Аннотация. Предложена, реализована и апробирована виртуальная лаборатория для проведения флеш-тестов солнечных панелей при стандартных условиях в поле. Результаты апробации показали следующее. Цифровой двойник способен предоставлять данные при стандартных условиях на основе полевых измерений. Прогнозы могут быть получены на основе реальных значений производительности. Виртуальная лаборатория для флеш-тестов показывает результаты, которые хорошо коррелируют с поведением модуля в поле.

Ключевые слова: Цифровой двойник, виртуальная лаборатория, фотоэлектрический, флеш-тест.