PROMOTING A SUSTAINABLE DIFFUSION OF SOLAR PV ELECTRICITY IN AFRICA: RESULTS OF THE CODEV PROJECT

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ABSTRACT: In this work we present the result of a collaboration between the Polytechnic Schools of Dakar (ESP) and Lausanne (EPFL) on the testing and monitoring of solar photovoltaic modules. The collaboration has involved the exchange of knowledge, methodologies and data, and, in particular, the analysis of the aging of PV modules exposed to the hot semi-arid climate of Dakar for eight years.
With the aim of promoting a focus on quality and reliability, the long-term goal of the collaboration would be to set-up a testing laboratory for PV modules and systems in Dakar and a training center. The testing laboratory will be working in close collaboration with the University and should potentially have a "lean" and easy-replicable structure.
The implementation of a third-party institution able to assess independently the quality of components and support system developers and installers in the design, commissioning and maintenance of PV projects is crucial to promote a "sustainable" diffusion of solar electricity in Africa, particularly when considering the residential and commercial/industrial rooftop PV market segment. By minimizing risk, focus on quality should promote a virtuous cycle leading to: (1) mitigation of financing costs of solar projects, therefore, considerably reducing the overall costs of this technology, (2) increase positive perception and awareness about PV.
Keywords: reliability, testing, international cooperation, emerging markets.

1 INTRODUCTION

Affordable and Clean Energy (i.e. ensuring access to affordable, reliable, sustainable and modern energy for all) is one of the 17 Sustainable Development Goals (SDGs), officially known as *Transforming our world: the 2030 Agenda for Sustainable Development*, set by the United Nations in 2015 [1]. At today's prices, and with a steadily declining price trend, solar photovoltaic (PV) electricity is increasingly perceived as one of the key-enabling technologies potentially leading to the achievement of this single target in those parts of the word where the access to electricity is still extremely limited. As for example in sub-Saharan Africa where 70% of the population (i.e. 600 million person) has no access to this form of energy [2].

In recent years, however, with a total (all Africa) cumulative capacity reaching over 2 GW in 2015, the market for new solar PV installations in Africa is expanding very rapidly [3]. Most of the new additions in capacity are covered by the utility-scale segments (e.g. South-Africa and Algeria in 2015), but rooftop (i.e. residential, industrial and commercial) as well as micro/pico-solar PV installations are experiencing similar growth rates, though official statistics covering these market segments are by far less reliable.

Nevertheless, the diffusion of rooftop PV installations in developing countries is often hindered by: (1) a poor perception about the reliability of this technology, and (2) by the relatively high up-front capital and financing costs, combined with a difficult access to credit [4, 5]. A promotion and sustainable diffusion of solar electricity in developing countries cannot take place if adequate control mechanism and quality checks (at component and system level) are not set in place.

The paper presents the results of a collaboration between ESP and EPFL that has involved the exchange of knowledge, methodologies, and data, and, in particular, the analysis of the aging of PV modules exposed to the hot semi-arid climate of Dakar for eight years.

As a follow-up of this initial collaboration, the paper addresses the issue (and relevance) of establishing a testing laboratory for PV in Senegal with the aim of promoting a focus on quality and promote a smooth diffusion of solar electricity in the region, particularly when considering the solar rooftop market segment.

2 EXPERIMENTAL WORK

A set of modules from different manufacturers has been exposed for eight years on the premises of ESP in Dakar (see Fig. 1), see [3] and [4] for a description of the testing facility and measurements methods at ESP. Dakar has a *hot semi-arid* climate (Köppen climate classification: *BSh*), with a short rainy season and a lengthy dry season. Other climates, which may be encountered in Senegal are mostly *hot-desert* (BWh) in the North and *tropical savannah* (Aw) in the South.

Figure 2 shows a map of Global Tilted Irradiation, (GTI) and solar electricity potential of Senegal for optimally-inclined modules [7]. With a yearly average of cumulative irradiation higher than 2000 kWh/m^2/y for all the country, the map clearly indicates the extremely good availability of solar resources in Senegal, and the large potential for solar electricity.

A characterization of a sub-set of modules has been performed at ESP after four years of operation and at EPFL in late 2016 (after 8 years). This has included visual inspection, Infra-Red (IR) and Electro-Luminescence (EL) imaging, and power (IV) measurements at STC of the modules exposed in Dakar for 8 years.

Fig.1: Researchers of ESP and EPFL on the outdoor test facility at ESP in Dakar.

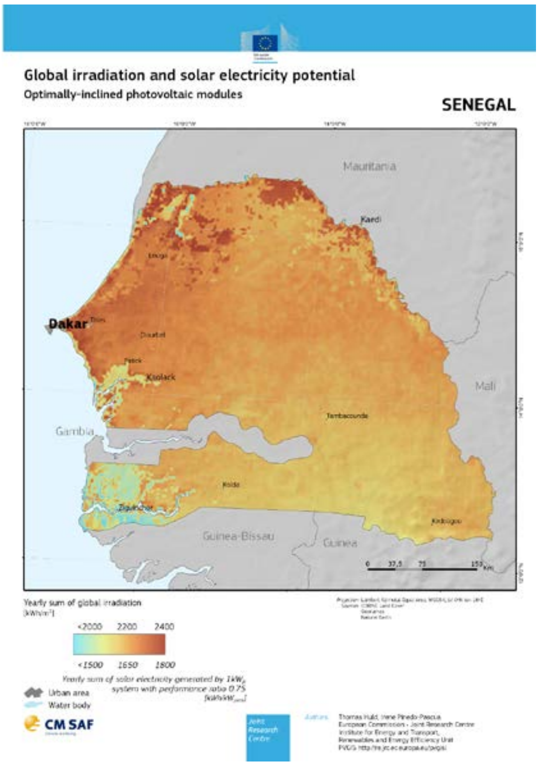

Fig.2: Map of Global Irradiation and solar electricity potential of Senegal for modules installed at optimal tilt [8].

At ESP, IV curve measurement were performed under natural sunlight with a portable IV tracer (IV HT400, see Ref. [6]), and at EPFL using a LED-Halogen based pulsed solar simulator that replicates the AM1.5 spectrum. EL and IR imaging were performed by applying a current corresponding to the short-circuit current (I_{sc}) to the modules by means of a power supplier.

3 RESULTS

For one specific module, representative of the whole set, the results of IV curve measurements are reported in Table I, showing the measured PV parameters before the modules installation and after 4 years of exposure, performed at ESP. The results of the measurements performed at EPFL after 8 years are shown as well.

In Table I, one can observe that the degradation trend is not consistent if comparing EPFL and ESP measurements, which proves the additional difficulty of assessing degradation rates when the measurement procedures (and possibly the calibration of instruments and sensors) are not constant during the years. It also highlights the necessity to have a good alignment and traceability to SI metrology standards of both measurement set-ups.

Table I: Degradation of PV parameters after exposure to the climate of Dakar for four and eight years, respectively.

	P_{mpp} [W]	V_{oc} [V]	I_{sc} [A]	FF [%]
Initial measurements at ESP	113.15	21.76	7.41	70.18
Measurements at ESP after 4 years	98.56	21.73	7.19	63.06
Measurements at EPFL after 8 years	110.69	21.51	7.49	68.7
Initial vs 4 yrs (%)	-12.89	-0.18	-2.90	-10.13
Initial vs 8 yrs (%)	-2.18%	-1.17	1.14%	-2.09%

For the same module, Fig. 3 shows results of visual inspection, EL and IR imaging performed on the modules after 8 years of exposure. The EL image highlights the presence of cracked cells, and the IR one the presence of hot-spot correlated with the presence of localized shunting paths.

Fig.4 shows the picture of a cell from the same module, exhibiting a pattern common to several of the modules installed on the roof (including modules from different manufacturers): i.e. the presence of decorated micro-cracks with burnmarks and discoloration of finger grids, in combination with a possible delamination of the encapsulant.

Finally Fig. 5 and 6 show how soiling can be a major issue in Dakar leading to current (and power) losses as high as -60%, particularly in the dry season. In particular, Fig. 6 shows an open junction box (J-box), belonging to one of the exposed modules, claiming IP65 protection against dust and water ingress, where the first and second digit refer to dust (6 = dust tight) and water protection (5 = protected against water jets).

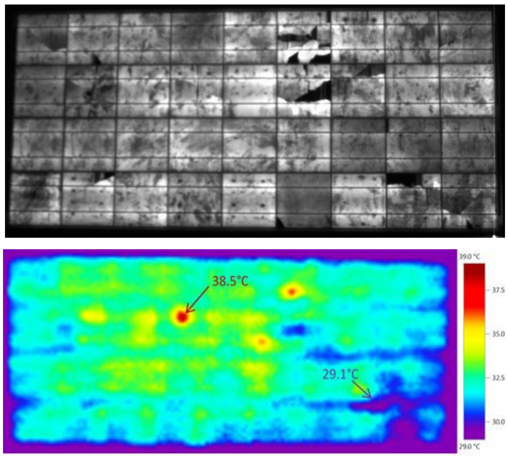

Fig. 3: From top to bottom: visual inspection, EL and IR imaging of a PV module exposed in Dakar for 8 years. Measurements were performed at EPFL in 2016.

Fig. 4: Particular of one of the cells of the module shown in Fig. 3, highliting the presence of decorated micro-cracks with burnmarks and discoloration of finger grids, in combination with a possible delamination of the encapsulant.

Fig. 5: Soiling can account up to 60% current and power losses.

Fig. 6: Open junction box, belonging to one of the exposed modules, claiming IP65 protection against dust and water ingress.

4 THE QUEST FOR QUALITY

As can be inferred by viewing Figures 3, 4 and 6 the quality of the modules (and other components) available in several African countries is often below standard, and, often, no compliancy to the meaningful international qualification standards (e.g. IEC, UL) can be proven. Most of the PV modules available for individual users or small installers are distributed through retailers with often a very limited knowledge about PV, who cannot offer any traceability about the origin of the products. Fig. 7 shows the picture of PV module available for sale on the street of a local market (Marché Sandaga) in Dakar. This combined with the sometimes extremely harsh climatic conditions that can be experience in several parts of the continent (from desert to hot and humid climates) can pose a serious threat to the long-term performance of the PV plants realized using these modules.

Fig. 7: PV modules available for sale at a local market (Marché Sandaga) in Dakar.

Another major barrier for a “sustainable” diffusion of solar PV electricity in Africa, is the level of training of system designers and installers, which should be supported by adequate training and qualification schemes. Professionals should therefore learn how to select the right components, how to design a system based on the project-specific requirements and constraints (e.g.

presence of shading, siting, budget, etc.). Similarly, adequately skilled professionals should be in charge of the installation, commissioning and operation and maintenance (O&M) phases.

By focusing on some of these aspects (quality of components and training), the long-term aim of the collaboration between ESP and EPFL is to set up a PV component test laboratory in Dakar which should be able to qualify modules available on the Senegalese market and certify minimal quality standards. This center should also serve as a hub for teaching and technical support between the University users, installers and project leaders as well as public authorities. Within the collaboration between ESP and EPFL, module test sites and dedicated monitoring equipment are being deployed in several University sites in Senegal. We thereby aim at further studing degradation and lifetime of modules in various types of sub-Saharan climates. In this context the presence of a test laboratory should offer additional access to data and experiences.

We believe that, if successful and adequately replicable in other contexts, the implementation of such a testing and training laboratory could really contribute in setting up a virtuous cycle, bringing to a “sustainable” diffusion of solar electricity in the whole continent.

Adequately trained professionals, combined with the possibility of verifying the quality of the components directly in the country, will prospectively have a strong impact on the bankability of small/medium projects, and therefore contribute in reducing the cost of financing of the projects. Cost of financing that, due to the large up-front costs of solar PV projects, constitute per-se a significant barrier to the diffusion of this technology. Another, positive side effect of would be that contributing in increasing the awareness and the positive perception of solar PV among the population.

5 CONCLUSIONS

Harsh climatic conditions such as the ones prevailing in Senegal seriously threat long-term module efficiency. This problem is even more acute given the often poor quality of the products available on the market. A collaboration between the Polytechnic schools of Dakar in Senegal and Lausanne in Neuchâtel to investigate PV module degradation and failure modes related to such climatic environments was started with the help of the Cooperation and Development Center of EPFL (CODEV).

As a follow-up of this initial collaboration, a testing laboratory for PV in Senegal is being set in Dakar with the aim of promoting a focus on quality and a smooth diffusion of solar electricity in the region, particularly when considering the solar rooftop market segment. This test laboratory should become an important actor of the PV value chain in Senegal and should offer, besides testing services, also education and technical advices. The center is also expected to become a valuable partner for future collaboration projects between EPFL and ESP to contribute to the understanding of module degradation in African countries and to establish technical guidelines for improved lifetime and quality.

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