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## IN OPERATION ENERGY AUDIT TO SUPPORT BIPV SUSTAINABILITY AND RELIABILITY

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**ABSTRACT:** The knowledge of the performance over time of energy systems and mainly BIPV is a major concern for public policy orientations. The development of solutions to achieve decarbonation and energy objectives must meet ever higher requirements for increasingly ambitious objectives in a context of development at an unprecedented pace. The answers provided focus on claimed performances supported by numerical approaches and controls at delivery stage. However, the performance of an energy system is affected over time by non-homogeneous and erratic phenomena that can only be apprehended by on-site measurement to assess the operating state of photovoltaic systems. In addition to characterizing the level of actual performance compared to expected, these operations can highlight the causes of the observed differences and determine solutions for correction. The purpose of this work is to identify ways to improve the overall quality of the BIPV sector through the energy performance indicator and to position BIPV solutions as a crucial contributor to achieve the objectives of the energy transition. Eventually, this energy indicator must interact with economic and environmental indicators. With self-consumption solutions, monitoring solution, often linked to the feed-in tariff are less and less accessible, which makes the means of performance monitoring and control “blind”. This article presents the work done to develop the method of quality control in operation of new and existing BIPV installations whose objective is to determine their real energy contribution and their role in the energy mix and expected production over the time.

Keywords : BIPV, Operating condition, Performance, Guarantee

### 1 INITIAL WORK

Since many years, CSTB is involved in IEA PVPS T15 program with the support of ADEME (French Energy Agency) to support development of BIPV solutions. Even more in current energy share and cost, the knowledge of global quality generation is a key point to give the correct drivers from decision makers to adopt PV and BIPV energy and disseminate over the countries sustainable and reliable solutions [1],[2].

Despite massive works on certifications (TC 82 – JWG11) dealing with specific BIPV concern with ongoing revision of EN 50583-1[3], regulations and construction codes, BIPV solutions meet barriers for a massive adoption, not exclusively based on cost. To overcome these barriers and have a representative inventory of the current quality and durability of PV and BIPV, a national survey addressed to French BIPV users is initiated, with the support of the BDPV<sup>®</sup> association. More than 14,000 installations are requested, and more than 4000 answers are collected and evaluated to specifically identify four categories of malfunctions. The data collected is cross-referenced with the data and classifications of insurers to ensure that the data collected can meet the challenges of the market. The first analysis of the data allows us to point out the representativeness of each category and to emphasize their impact on the degradation of performance and this over time.

Four main categories are identified even if large progress have been done, many messes are revealed and remain relevant and highlight progress to be made.

Important notes highlight the extreme low rate of remaining defaults (close to 10% of installation). Fists results underline that main issues are not found on expected categories as water leakages or fire risks but

mainly on energy production and electrical defaults. Two well managed considered categories. Less remarkable these two categories significantly affect installation numbers and results in negative contribution on LCOE, ROI and global warming reduction rate.

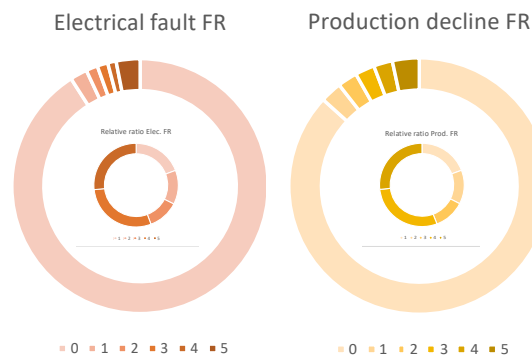


Figure 1 : Electric and energy production defaults detected. Outer ring expresses global rate of defaults, inner ring the relative rate

The two main representative categories affected by defaults are showed on Figure 1 with two different rings expressing the global rate of risk from 0 (null) to 5 (extreme). In the inner ring, are displayed the relative default rate (from 1 to 5) to underline the weight of default gravity. At any stages defaults are well identified.

For these two fists categories, the rate of appearance is 11% and 16% respectively for Electric and Production defaults. The rate reaches 8% and 4,8% on respectively Water leakages and Fire defaults, as showed on Figure 2. Considered as mastered defaults are unfortunately the most present with long terms effects and could contribute largely to discriminate the use of BIPV. These results highlight the large work performed to develop specific

assessment to reduce risks of water or mechanical damages and fire risks. Extended work performed by experts of T15 provided relevant inputs to give correct drivers for BIPV solutions. The last report on fire risks and labs involved to assess correctly BIPV components[4], is a part of this global improvement to manage and avoid fire hazards.

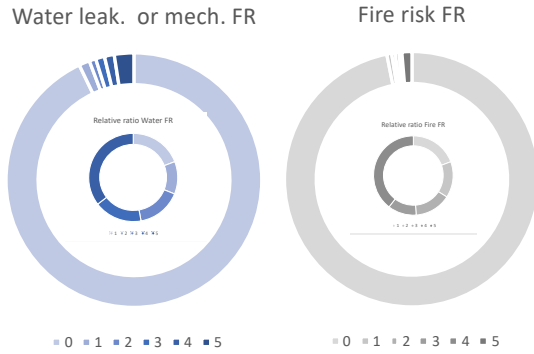


Figure 2 : Water leakages and Fire risk defaults detected. Outer ring expresses global rate of defaults, inner ring the relative rate.

This first investigation highlights the lack of knowledges or the lack of technical supervision on BIPV installations, where defaults are estimated as insignificant. Even if default rate is about 1% on global amount of PV installation, we could assume that 1.61 GWc over the EU countries are affected by and cut energy production by 1,58 TWh in 2022 [5], and the current growth of BIPV market could expect to much more impact. To find a way to reduce these issues we conducted research on default identification methodology to prevent default and support maintenance work for an optimal energy production of BIPV installation.

## 2 PRELIMINARY METHODOLOGY

The development and implementation of this method is based on a preliminary work based on literature review [6] with two main objectives, a) characterize failure modes and detection methods and b) Rank and identify the most critical failure modes. This State of the art on photovoltaic failure modes and detection methods allows to count 26 failure modes and up to 13 detection methods. Interactions between failures and detection methods are showed on Figure 3. A rank failure methodology is expressed via FMECA analysis using three scores parameters: Severity (S), Occurrence (O) and Detection (D).

A Risk Priority Number is expressed (RPN) on the base of these three parameters, with D is an addition of market maturity parameter (M) and the intervention cost parameter (C). RPN is expressed as the following equations and can be computed.

$$RPN = S \cdot O \cdot D$$

Eq. 1

$$RPN_{RMS,K} = \sqrt{\frac{1}{N_S} \sum_{n=1}^{N_S} RPN_{k,n}^2}$$

Eq. 2

This method aims at mapping BIPV failures and

ranking them based on their risk and identify the severity of defaults, the occurrence rate, and the detection ability. RPN is tie linked with LCOE and cost impact of defaults. To combine results of this literature review and main BIPV defaults collected from field, on site validation is necessary to fine tuning the methodology to specific BIPV sets and expectations. Validation campaigns are conducted on CSTB experimental platforms and real installation sites to validate approach.

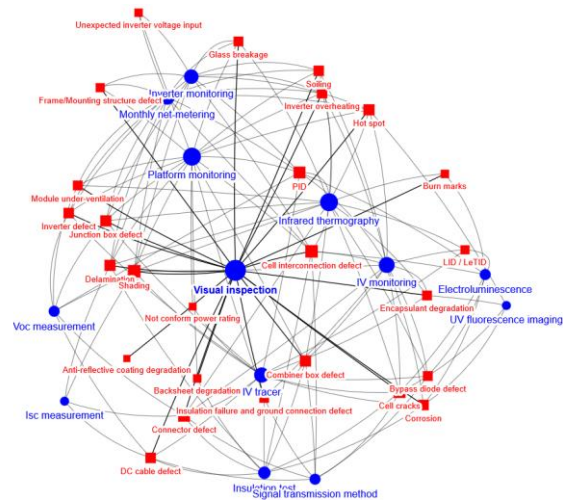


Figure 3 : Network map of failure and detection method.

## 3 VALIDATION PROTOCOL

As expressed in the preliminary work, on site check and validation is necessary to bring confidence in RPN score and control the failure mode. The ranking must be improved by on site audits and visual controls with appropriate equipment. The Figure 4 shows general RPN score for any PV installation, a dedicated figure will be generated after on site measurement to consolidate feedbacks and method accuracy.

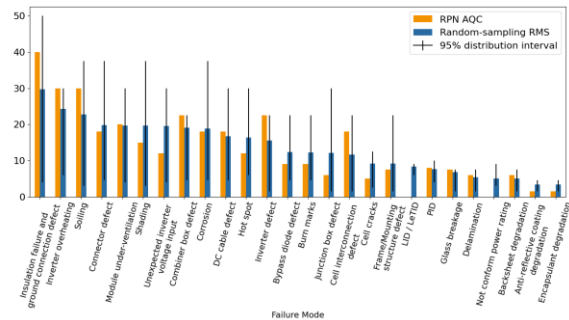


Figure 4 : RPN score according to statistic failure mode.

For each BIPV installation the RPN score will be to validate in front of the complexity of each BIPV category as described in [3] and according to the extended list of each failure case  $k$ , conditions of the power systems and to check their technical sets. Indicators, ENERGY and ELECTRICAL are the two main elements that are audited so far. To do so, an adapted equipment and an intervention procedure is currently being finalized and validated on test platforms to determine the duration, accuracy of sensors, measurement solutions, components and equipment. Duration and costs of such operations are still monitored.

The verification of the effective quality of an installation should have the lower possible impact on the

LCOE and should allow improving the reliability and durability of BIPV installations.

The large-scale deployment of this method, on new as well as existing installations, must above all identify chronic malfunctions and provide corrective solutions that will allow the improvement of the entire sector based on dynamic and statistically representative feedback.

These corrections are as much physical as numerical, since the measurements carried out on sites will be compared with the estimates of productions carried out with the numerical tools and will make it possible to bring corrective actions based on real data and thus to improve the base of knowledge of the operation of the BIPV.

### 3.1 Validation in controlled conditions

First stage of validation is performed on experimental platforms and PV lab of CSTB to validate in high end accuracy conditions measurements and visual control. Additional investigations on damaged module, measured and provided by CERTISOLIS, French certification body, as reference measurements are also carried out to control effect of default typologies and well-known damages (cracks, soiling, yellowing) and validate impact on expected energy generation. CSTB experimental setups, allow to validate methodology on many different BIPV solutions, as roofs, cladding façades, insulated glazing solution and canopy.



Figure 5 : Canopy mockup on CSTB plateformes – Onyx Solar® modules in BIPVBOOST project – 0,9 kWc.

Controlled conditions in laboratory allow to validate methodology and identify the weight contribution of any identified issue including damage or climatic and surrounding conditions. The Figure 6 shows the gap between STC conditions and in real operating conditions including all production hazards and aging effects.

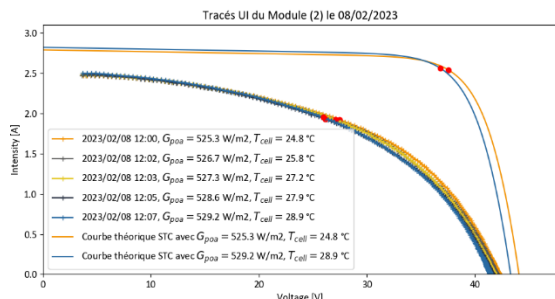


Figure 6 : Example of deviation observed between STC condition and in operation conditions.

Correction are applied on calculation prediction taking into account natural deviation of PV parts and external contribution from surrounding conditions.

### 3.2 Validation in real operating conditions

Second stage aims to face to face controlled conditions

in laboratory to real operating conditions to correct methodology with constraints from real field, as operating time, access constraints and unknow data. Main part is to take real operating conditions as temperature balance, local climates conditions, and shadowing effects. Several sites are selected to have relevant representativity of French BIPV installations. Key point is to have as close as possible similarities between BIPV categories to define or detect underperformance by category for a higher results accuracy.



Figure 7 : Canopy on ADEME building – 2ES company – 26 kWc

Same investigation process is applied on operating installations as showed on Figure 7, a large canopy in operation from almost two years. Measurements on strings, DC parts, bring us comparison results and estimation of possible degradation of self-aging, soiling and temperature balance tied to integration mode.

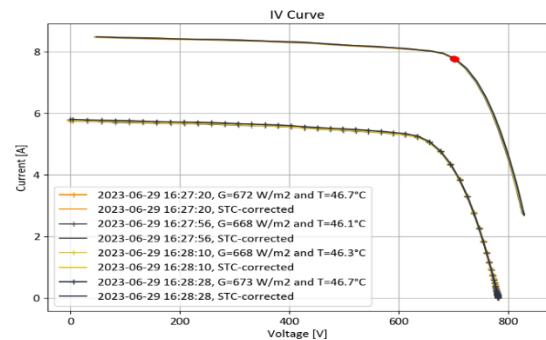


Figure 8 : STC correction of on-site measurement. Gap integrated in numerical expected production.

In lab or experimental platforms results and in real operating condition results are then compared in order to consolidate methodology validation of defaults detection or deviation to identify possible solution to resolve underperformances and maintain the highest possible level of energy production.

This approach aims to distinguish issues coming from BIPV system themselves and those coming from surrounding environment. Another item is to point out undercalculation or mistakes or inappropriate data in the use digital tools.

## 4 RESULTS REPRESENTATION AND OVER THE TIME DEPENDENCE

A generic graphic representation is attempted to make the investigations carried out more intelligible. The technical dependence of the category will be an important point for the final representation of the current graphs.

### 4.1 Graphic presentation results

A color code is used to express every stage of methodology with the location of energy performance index level by a colored circle. Projection on expected energy is also represented to give trend of optimal normal evolution and lower expected estimation (colored parallelogram) over the time. Deviations from initial calculation, commissioning and different audit carried out on site are also displayed to underline gaps between any stages and impact on final energy production. Following figures express the step-by-step progress of the methodology, starting with the Figure 9, and the representation of expected energy produced by the installation according to installer's calculation and reference simulation using reference tools.

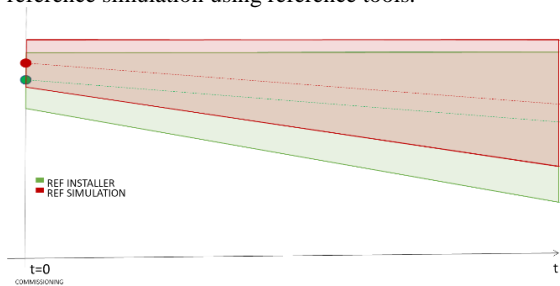


Figure 9 : Reference values (green) of expected energy from installer and by simulation (red), time projection.

On-site audit provide crucial data that allow corrections to be made on simulation results, linked with real operating conditions. Th shift induced by on site data correction is showed on Figure 10 and could be significant.

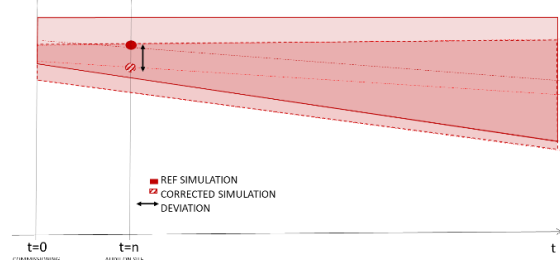


Figure 10 : Corrected simulation (striped red) including collected data and measurements during on-site audit. Deviation displayed (black).

#### 4.2 On site measure implementation

Then, the next main stage is to perform on-site measurement in order to display results in operating conditions. As showed on Figure 11, the difference between ideal energy forecast (green) and on-site measurements are quite different, and expected prevision over the time could be far each other.

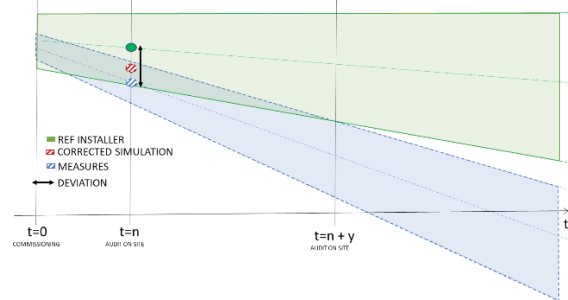


Figure 11 : On site measurement (blue) energy status compared with reference (green) and corected simulation

(striped red) - Final deviation dysplayed (black).

An on-site carried out measurement appear to be an essential step of this methodology, allowing to integer in the PR calculation or on the Energy Performance Index all underperformances that could affect a BIPV installation not reachable without an on-site investigation. If long terms degradation as soiling, dusting, or aging could be simple taken into, more unpredictable degradations could significantly affect BIPV production without an accurate identification of causes. Interest of regular audits is to provide higher level validation of the methodology presented, including BIPV category, and bringing more confidence in the identification of causes of energy degradation.

#### 4.3 Time dependance

Stages of this methodology aims to identify BIPV power underperformances and effects on quantifiable indicators as PR, Energy Performance Indicator or Energy Yield. A significant step forward is to consider not only commissioning time but to integer significant influence of time, often considering as aging but not only.

If standard deviations are due to component or system themselves, identified as photovoltaic losses (temperature losses, natural aging, inverter losses...), another set of factors comes from environment stresses or from initial faults (design, poor quality commissioning...).

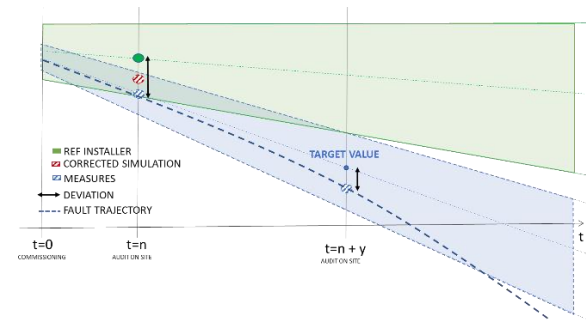


Figure 12 : Over the time audits, expression of faults trend and deviation on expected trajectory. Target value (blue dot) and on site measurement (blue circle).

As an exemple,  $t=n+y$  time audit could give a state of large deviation far from expected deviation (target value) and to bring un inappropriate deviation (blue dashed line) and affect significantly ordinate value as showed on Figure 12. Faced with this type of deviation, an investigation on site is carried out to identify the causes of deviation and Figure 3 network is also updated to make future defect identification estimates or prediction more accurate. This data processing.

#### 4.3 Lessons learned.

Validation of this methodology to support in operation performance measurement of BIPV solution, provide us many lessons learned on necessity to control and supervise quality and evolution over the time on BIPV. First underline the role of audits that are essential not only to validate methodology but also to point out exact issues. Then audits are strengthening even more the accuracy of the self-detection brings by this method and the statistical issue identification, linked with BIPV category.

Secondly, this incremental loop is essential in this

process and make more precise methodology results to support in operation performance of BIPV installation over the time.

Even if performance guarantee for BIPV solution is crucial for supporting large dissemination, issues or abnormal deviations are still regular and a best know of possible defaults is essential to bring confidence in the use of renewable energy and achievement of green energy contribution in the energy mix.

## 7 RESULTS AND CONCLUSIONS

Stages of this methodology aims to identify BIPV power underperformances and effects on underproduction and collateral effects on energy payback time and contribution on climatic change.

This method is currently being applied on the experimental platforms of the CSTB where different BIPV solution are under supervision and selected real installations for a final validation. Equipment and the intervention procedures are crucial points to perform a state-of-the-art audit according to relevant standards [8], [9] and provide valuable data for the quality state in operation but also extrapolated expected energy generation.

The identification of possible defects and the modalities of corrections to be made will also be organized and classified to feed a database that can be exploited and extended beyond France. To support these investigations, dysfunctional modules have been provided by CERTISOLIS (case studies) and are used to identify pre-identified categories of pathologies that will make it possible to determine the level of dysfunction of BIPV installations.

On site validation appears to be essential at the current stage of methodology development, but expected results is a full automated data processing allowing to provide accurate estimation of energy deviation with an identification of possible defaults occurring to define appropriate action.

## 8 NEXT STEPS FORWARDS

Firsts results are convincing on the detection of many deviations from initial study to operating condition. Defaults from the beginning, starting from commissioning, to issues over the time are affecting significantly BIPV installation and must be detected with a high accuracy to mandate maintenance and preserve expected energy generation over the time. Computation of all collected data will allow to predict possible deviation or by identification of deviation trend, and cause identification will provide more confidence in the use of BIPV by increasing sustainability and reliability.

to make this method completely operational and functional, and easily adopted by stakeholder, capability to learn over the time and integer new BIPV solutions or new influencing parameters not already identified is important. Next step forward will be to introduce BIPV sub-family categories.

Final expectations of this methodology are not only dealing with energy performance even if it's the first concern. Results obtained are expected to provide recommendation for all BIPV value chain, from planners to installers, and give the good drivers for investors and insurers. As a direct output, identification of weak points

and ranking of default sensibility of BIPV could be applied. Maintenance recommendation as well as specific training could also be identified to streamline on-site intervention and reduce downtime of energy generators.

Continuous implementation of issues will make possible to determine the weight or contribution of each defect on performance indicator and to propose targeted progress operations dedicated to each BIPV categories.

Validation on further sites is under progress for a general application, including weather or climate sensitivity, aging, BIPV category, maintenance operation. Investigation with other countries with different concerns, regulations or codes for a universal solution is in the scope of the next works.

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