QUANTIFICATION OF LOSSES CAUSED BY DYNAMICALLY CHANGING SHADOWS IN MULTI-MW PV PLANTS BASED ON COMPUTATIONS ON TOP OF MONITORING

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ABSTRACT:
This paper is a practical report including lots of theoretical background and the experience of more than five years of operating and monitoring of more than 850 MWp large scale PV plants, located all over Europe, O&M Supervision done by AES, and more than 70 MWp small and medium sized PV plants located in central Europe, O&M coordinated by Greentec Services.

All parks have overall performance exceeding the predicted energy yields.

Fig 1: Basic situation with trees on border of park

The goal was the development of a methodology to quantify the effective losses on dynamically changing shadows like

- Growing plants in or near to where the plant is based
- Leaf stripping and leaf growing effects on broad-leafed trees shadowing the modules
- Failure to cut grass/to cut grass at scheduled times

in large PV-Plants with a size of more than 5 MWp.

The challenge was to create a tool applicable to all of our parks that delivers a precise as possible result to enable decision making based on cost/benefit analysis about corrective activities like cutting vegetation at the most economically feasible time.

We will present results and impressive special effects of large PV plants verified in all of our parks including:

- Reasons why simulation is not economical, especially in large plants
- Reasons for underestimation of the real amount of losses in usual situations
- Basics of the methodology, including tips to avoid side effects
- Impressive details of some local effects
- Details of sample parks including pictures and annual effect distribution
- Summary of all of our parks

Purpose of the work: Development of a tool to enable decision making around need and best time for cutting activities based on best possible evaluation of effective losses caused by shadows from unsteady growth of vegetation.

Approach: Using historical data of string monitoring to build for every string a unique model and use this for the evaluation of the losses caused by the dynamically changing shadowing effect.

S**cientific innovation and relevance**: Unique large amount of monitored values, handled with new techniques for generating local models to quantifying losses in Multi MW PV Plants.

Results and Conclusions: Significant improvement of accuracy for deciding on cost effective activities to keep and improve performance of Multi-MW PV Plants.

Keywords: large Grid-connected PV systems, Energy performance, System performance, Monitoring, Defects, Shading, Plant Control

1 INTRODUCTION

The long term yield stability and operational safety of PV plants are primarily dependent on the longevity and reliability of the modules and system technology components used. Quality control of single components usually includes visual checks, performance measurement, thermal imaging and electroluminescence testing, etc. However, in Multi-MW PV Plants this can only safeguard that all components meet the necessary requirements at construction and operational phase. Recognition of faults and further risk reduction of technical failures during the 20-25 years operation time cannot be covered by even permanent monitoring to guarantee optimum performance. One of the most underestimated failures is the impact of shadows, which did not exist at the time of construction or during the usual due diligence at the start of operations. Vegetation in and near the park is outside of the scope of the technicians operating the park and taking care of electrical perfection.

Alternative Energy Solutions GmbH (AES) acts as an Owner Representative Advisor and coordinates, in this function, asset management as well as operation and maintenance of more than 850 MWp photovoltaics. Based on the handling requirements of these huge assets a special software toolset, the Performance Improvement Tool “PIT”, a special analysis toolset with computations on top of monitoring, was developed and helps other O&M supervisors to control and improve their assets.

Greentec Services GmbH is one of AES’s technically most competent clients to use PIT to get more precise knowledge about details in the PV-parks that they support with operation & maintenance services. Combining the different size and location of the serviced plants guarantees that the single tools suit a wider range of different PV plants.

The main focus of our work was the development of a tool to decide on the requirements and timing for cutting activities. Therefore the best possible evaluation of effective losses caused by shadows from unsteady growth of vegetation was used to get clear decisions about economically feasible activities of the corrective activities.

We showed that the major problem in evaluation of the complete loss in large plants are many local differences on the effects. It is not possible to take single situations and make estimations for the whole PV-plant. This is one of the main reasons why a solution by taking simulation software is economically not feasible, especially in large plants with more than 5MWp per unit.

2 CHALLENGES TO ACHIEVE ACCEPTABLE RESULTS

A more detailed view of the mission made some of the pitfalls more obvious.

Fig 2: Unsteady border of shadow

Caused by the size of the parks we had to consider a lot of discontinuous side effects like

- Different growth rates of different kinds of vegetation a specific locations
- Different distribution of leaves and branches on different trees
- Different module cooling behaviour near the border of the shadows
- Local wind caused by local temperature differences between sunny and shady regions

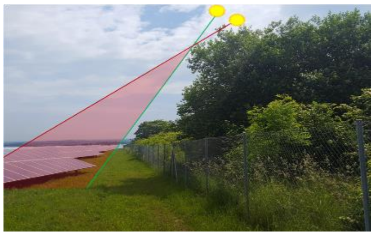

Fig 3: impact on small change to sun angle

Apart from the challenges of the effects of discontinuous growing vegetation we had to consider the irregularities of the local weather situation like

- Local weather effects of sunny afternoon hours on cloudy weather the rest of the day
- Unexpectedly long periods of shadow during sunny winter days
- Foggy days with only ambient irradiation for a longer time

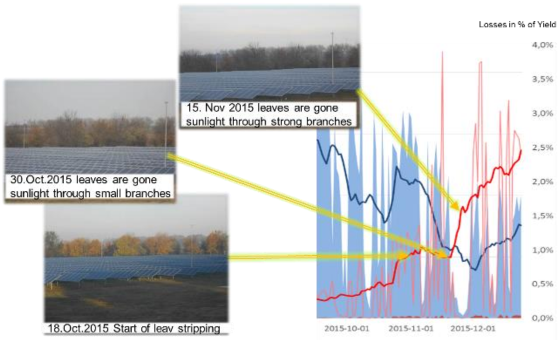

Fig 4: Reduction of shadow effect when leaves are falling

3 METHODOLOGY

Taking all of these effects into consideration a dynamic loss profile of the park has to be evaluated as a major step to gain a unique profile for every string. The following chart shows the number of infected strings at defined dates where clear weather situation allowed a precise evaluation of the sun height where shadow starts to have significant impact.

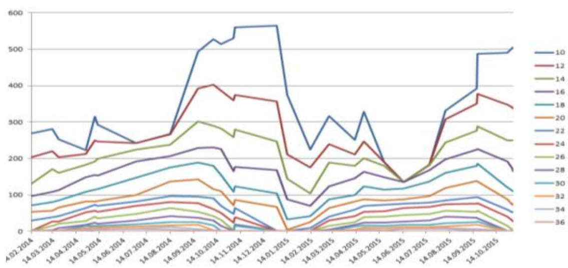

Fig.5: Number of strings with sun height for influence at defined level

Based on this global impact indication for every string the critical sun height for every string is calculated by generating a function for start of impact with respect to sun height.

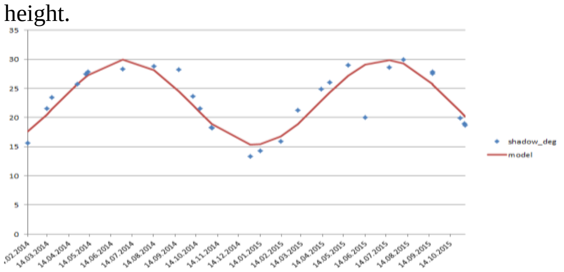

Fig.6: Influence curve of one string. If angle is above red line shadow is not possible and further calculations can be skipped.

This unique function for every string is taken for comparison between normal illuminated strings and shadow infected strings during all timeframes where effect is relevant for specific string. The example in the following chart shows the impact of trees over a segment of 600 m near outside the border of a 34 MW park. The annual losses in 2015 only by the effect of the growing trees have been 165.000 kWh, which was unexpectedly high. The yellow arrows point to the effect of leaf growing and leaf stripping which is compensated as soon as the sun height is at a level that the shadow is released more by branches than be leaves (orange arrows)

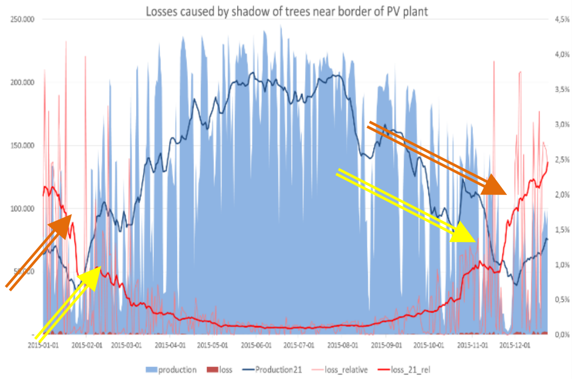

Fig 7: Park production and losses for 2015

To obtain a better impression of the different effects we also used methods to smooth the results without losing accuracy on the loss summary.

To evaluate the losses we used the monitoring values of every string in 1 minute timeframes and filtered all values where the effect is not valid for each string.

We showed the overview of the results of all our parks and highlight some specific details.

There are parks, where the costs for cutting will not exceed the losses, as well as unexpected high losses in underestimated situations.

4 EXAMPLES OF APPLICATION

We analyzed all parks with significant vegetation at the border and presented the results of 2 Parks

PARK 1

- Size: 34,14 MW,
- Location: Odessa Region Ukraine
- 141.812 Crystalline modules (230Wp-245Wp)
- 52 Inverter a 630kVA
- Start of production: 2013

Fig 8: aerial view to PARK 1 including locations of trees and infected strings

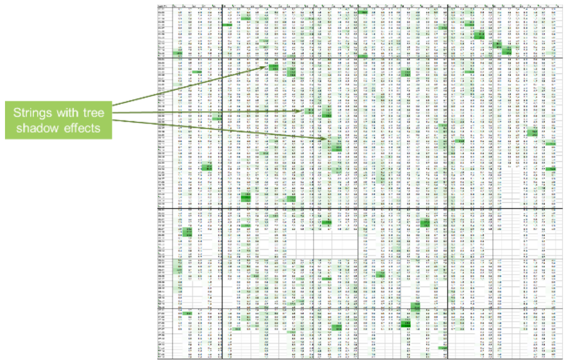

Fig 9: String Performance map for Park 1 logical view to infected strings

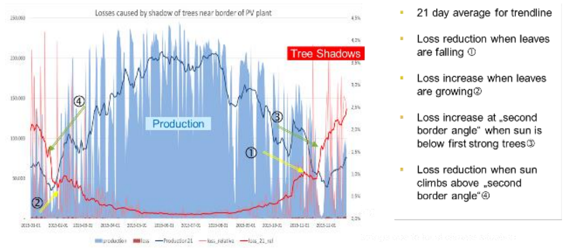

Fig 10: Daily production and level of loss

It is clearly visible, that on days with low production the percentage of impact is growing dramatically

PARK 2

- Size: 6,1 MW,
- Location: Germany
- 24.680 Crystalline modules (230Wp)
- 44 Inverter a 125kVA
- Start of production: 2011

Fig 11: aerial view to PARK 2 including locations of trees and infected strings

An unexpected result of our investigation was caused by different local climate situations and the need for more reference strings to compare local losses.

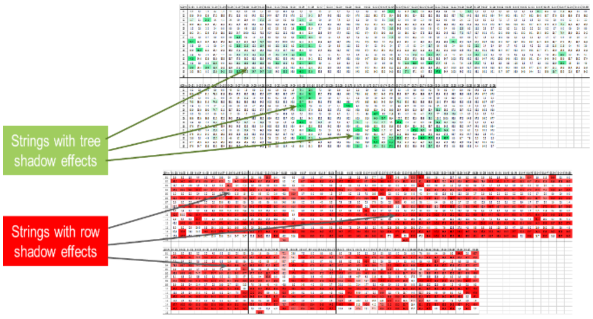

Fig 12: String Performance maps for Park 2 logical view to infected strings

In this park the problem of a very tiny gap between the module tables forced us to split the effect between raw shadow effects and tree shadow effects.

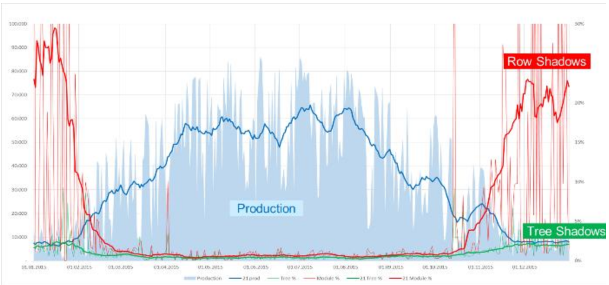

Fig 13: Daily production and level of loss

Here it is clearly visible that the impact of raw shadow in this park is significantly more than the tree shadow effects.

5 FINALLY QUANTIFIED RESULTS / IMPACT 2015

We got final results on the losses that we could identify as a tree loss with:

PARK 1:

Tree losses 190.000 kWh (0,4% of annual yield)

PARK 2:

Row shadow losses

257.600 kWh (1,96% of annual yield)

Tree losses 71.600 kWh (0,54% of annual losses)

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