

Mismatch in typical commercial rooftops in the Netherlands

Objective

PV modules produce maximum power at a specific working point (Maximum Power Point – MPP) which is achieved at a specific current (I_{mpp}) and voltage (V_{mpp}). Mismatch between modules occurs when modules that are connected in series require different combinations of voltage and current to generate maximum power.

Extensive research over the years has shown that mismatch can result from numerous factors including manufacturing variance, thermal gradients within the array, uneven surface soiling, partial shading, uneven degradation and more. More information on the sources for module mismatch can be found in the article "[Moving Forward to Module-Level Power Optimization](#)".

When modules with mismatch are connected to a traditional string inverter, the inverter must optimize all modules simultaneously, so that the power point is suboptimal to most, if not all modules. Therefore in traditional inverter systems, mismatch between modules leads to power losses.

In a study [published](#)¹ in the Journal of Solar Energy Engineering it is estimated that **power losses associated with inherent mismatch between modules represent approximately 10% of the total generated power.**

This paper will demonstrate mismatch between modules in four typical rooftop installations in the Netherlands, as revealed by the SolarEdge monitoring platform. Even though the installations are different in location, module type, installation company and installation date, they all show module mismatch.

¹ Analysis Model of Mismatch Power Losses in PV Systems, Aissa and Silvestre, 2009

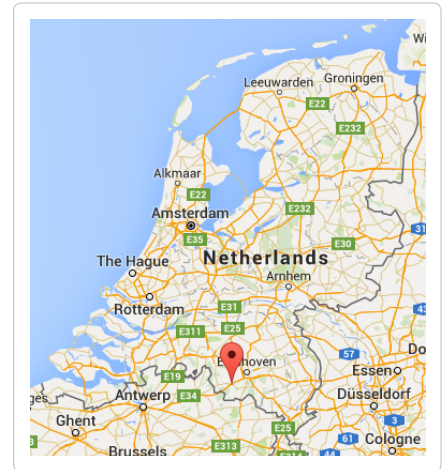
Example I - Aging Mismatch

Site I

Size: 1.63MWp

Installation date: 6 August 2012

Module used: Trina Solar TSM-DC14 285Wp



After almost 4 years of field operation, indications of module degradation began showing. Since modules age at an uneven rate, the level of degradation is uneven, causing wide mismatch between modules in the same string. Figure 1 below shows a 17% mismatch on the yearly total between best (15.2.18) and worst (15.2.23) modules. A daily 10% mismatch can be seen between these modules (Figure 2). Similar mismatch can be observed in multiple locations across this 1.63MW site.

Photos of the array (Figure 3) do not show any particular soiling or damage that could explain the large variety between module outputs.



Figure 1: Layout view showing yearly energy production for string 15.2. Significant mismatch between adjacent modules and modules in the same string is observed

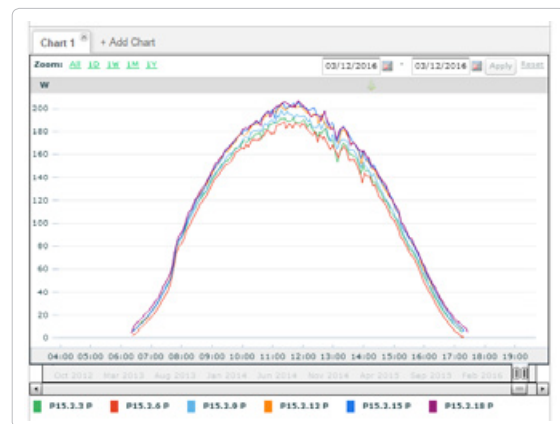


Figure 2: Power curves showing a daily mismatch of up to 10% between modules in the same string



Figure 3: Photograph of string 15.2 does not reveal an apparent source for the mismatch between modules in the string

Example II - Dynamic Weather

Site II, <10km from the ocean

Size: 181kWp

Installation date: 31 July 2015

Module used: Suntech Power STP275



Looking at the system's layout in a yearly view (Figure 4) reveals small differences in modules' production, as represented by the different shades of blue



Figure 4: Layout view in yearly resolution demonstrate color variation implying on mismatch in modules' energy production

Zooming in to daily power production curve, the impact of the ocean proximity, and the dynamic cloud fronts is visible



Figure 5: Power curves demonstrate transient shading patterns on individual modules, implying dynamic cloud fronts partially covering the array

EXAMPLE III - INDUSTRIAL SOILING & SHADING

Site III

Size: 2.4MWp

Installation date: 9 November 2015

Module used: Risen RSM-60-6-260P



Plospan is an industrial plant for wood processing. The modules in the system are constantly being covered by dust and pollution from the huge chimneys of the factory and from trucks unloading dusty raw materials (Figure 6).



Figure 6: Trucks unloading dusty raw materials and smoke coming out of the Plospan chimneys generate soiling mismatch

Figure 7 shows the saw dust loading bay. The dust creates a gradient of soiling on the modules, so that the modules closest to the doors are dirtiest. A different amount of soiling leads to a mismatch between the modules (Figure 7). Modules covered by dust are exposed to lower levels of irradiance and therefore produce less energy compared to less covered modules (Figure 8).

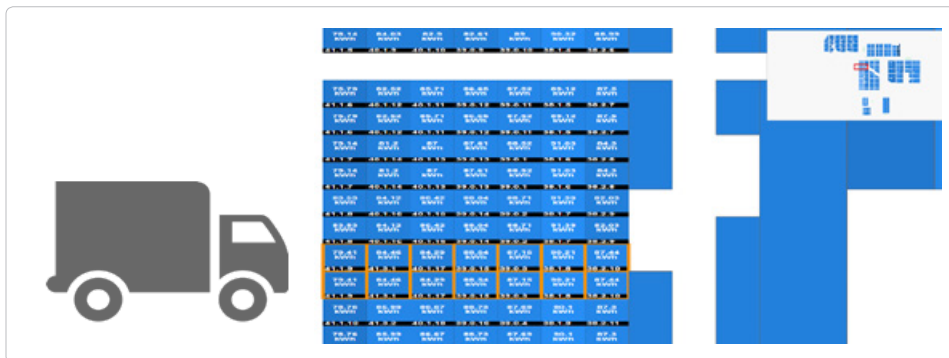


Figure 7: Layout view of the array closest to the unloading dock, showing that energy production increases with distance from the pollution

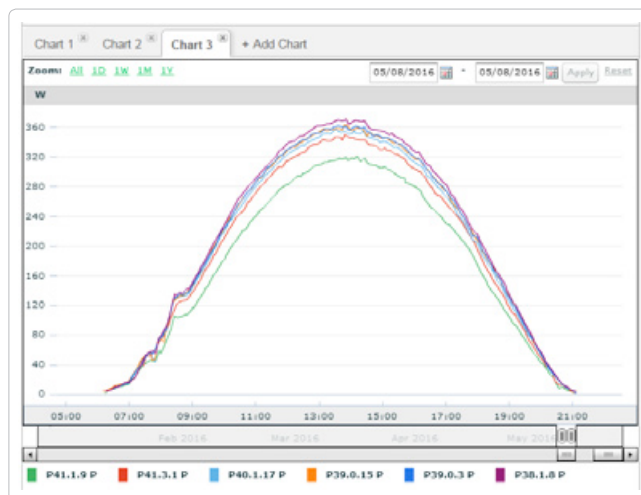


Figure 8: Power curves show that modules on strings closest to the unloading dock (41.1.6) are producing the least energy

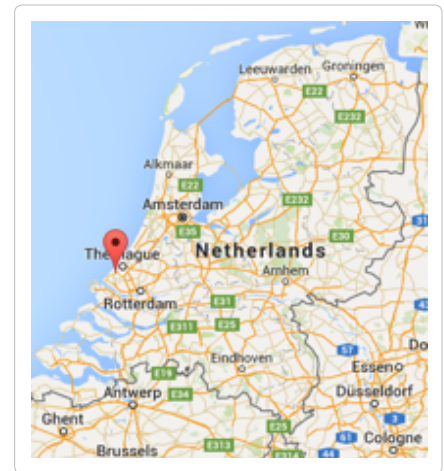
EXAMPLE IV - INHERENT MISMATCH

Site IV, <5km from the ocean

Size: 4.5MWp

Installation date: 1 March 2016

Module used: Jinko Solar JKMS-260P-60



In a newly installed site with modules flash tested and sorted in bins, little mismatch can be expected. However, in this 3 month old site, we can already spot mismatch between modules (Figure 9)



Figure 9: Layout yearly view shows the mismatch in energy production between modules in the same string

There is a 7% difference between best (13.3.36) and worst (13.3.39) modules in the string (Figure 10)

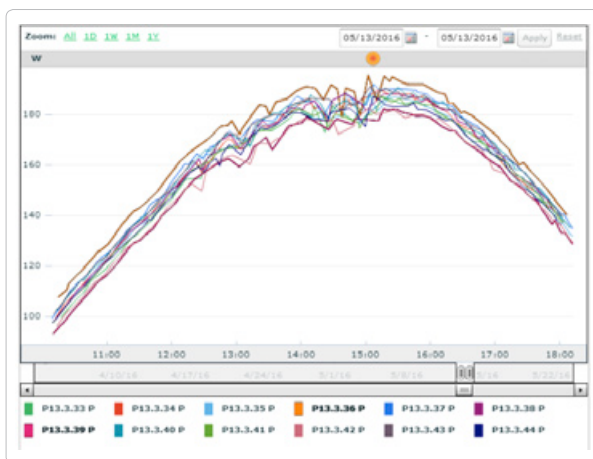


Figure 10a: Power curves show mismatch between best and worst modules in the string



Figure 10b: Power curves demonstrate 7% mismatch between best and worst Modules at 4pm

Looking at the modules' voltage (Figure 11), it can be clearly stated that this is not a voltage mismatch, and therefore it is concluded in our opinion to be a current mismatch, which – in a string of modules connected to a traditional string inverter – drives power losses. Since these modules are individually managed by power optimizers, these power losses are eliminated.

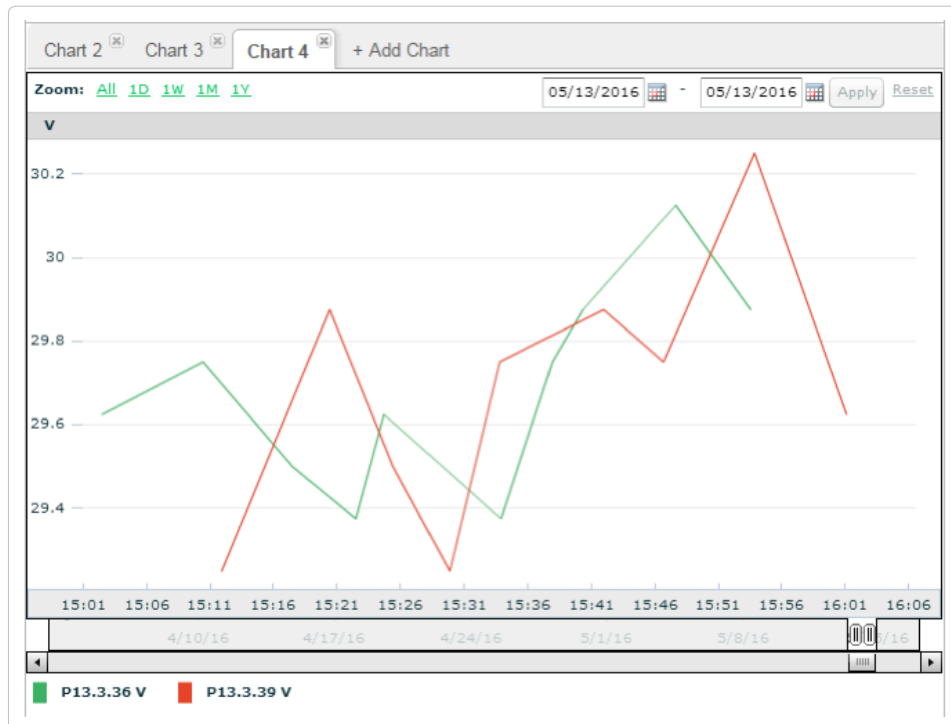


Figure 11: voltage curves are similar for the best and worst modules

Summary

This paper shows that mismatch between modules exists in each of the four rooftops examined, irrespectively of the installation's location, age or module type. It is likely to assume that most, if not all PV installations exhibit a similar level of mismatch which can result from soiling, partial shading, inherent variances, temperature gradient and other factors. This mismatch is bound to grow with time, as modules degrade at an uneven rate.

Traditional string inverters optimize power production at a string or array level. It is therefore reasonable to assume that mismatch-related power losses are relevant and inevitable in every traditional PV installation.

When applying power optimizers at the module level, they adjust current and voltage to the optimal working point of each module. Modules are therefore working at their individual maximum power point, to eliminate mismatch-related power losses and increase the total system output.