Plant Efficiency Analysis: Operating Point vs. Pmp
Assessing The Energy Left on the Table

1. Problem Statement

Ensuring sites are yielding as much energy as possible is a critical component of asset management. Unfortunately, expectations about site performance are set by models which are created before a site is built.These models are rarely tested or verified once a site becomes operational, leaving room for critical forecasting errors that complicate all aspects of site management. Losses at the module, string and inverter levels are difficult to differentiate from standard performance data. It is even more difficult to assess both causes and costs. How can we assess the performance loss in real time?

2. Our Approach

Module-level IV curves are taken *in isolation* from the rest of the field to assess what the PV module *could* do at a moment in time, recorded as the Maximum power point (Pmp). The MSI IV DAQ also records what the module is actually doing, i.e. the Operating point (Pop) of the module, prior to doing each IV sweep.

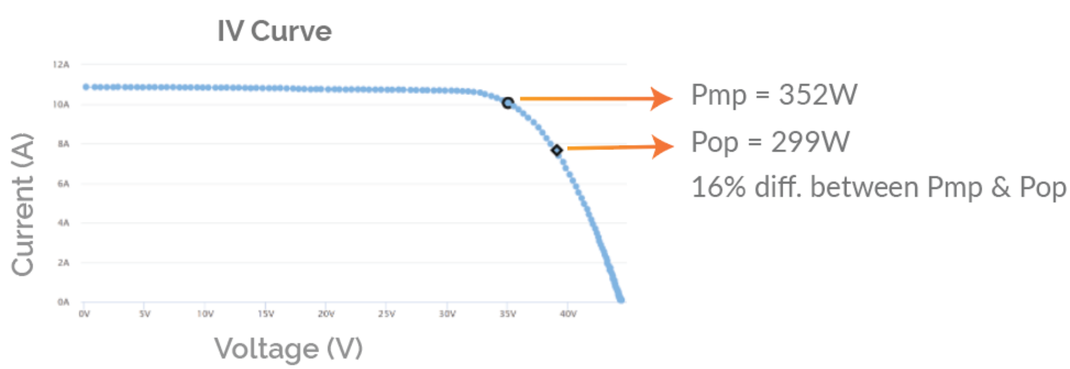

Figure 1: Discrepancy between Pmp and Pop

Comparing these two measurements at select modules across a site sheds light on the performance and health of the rest of the plant. Morgan Solar has developed analytics to differentiate between different loss factors such as:

- Intra-string mismatch (within a string e.g. module variability, shading effects)
- Inter-string mismatch (between strings)
- Inverter losses (Downtime, inverter clipping, MPPT tracking issues, etc)

Morgan Solar is often called upon by our clients to deploy our IV DAQ system to help quantify unidentified losses. This study investigates loss factors between modules, strings, and inverters over a 1 month period, and quantifies the energy impacts of those losses.

3. Results

This is a case study of real-world data from 6 modules on 2 strings on different inverters. This performance analysis compares performance of two strings over the course of a month.

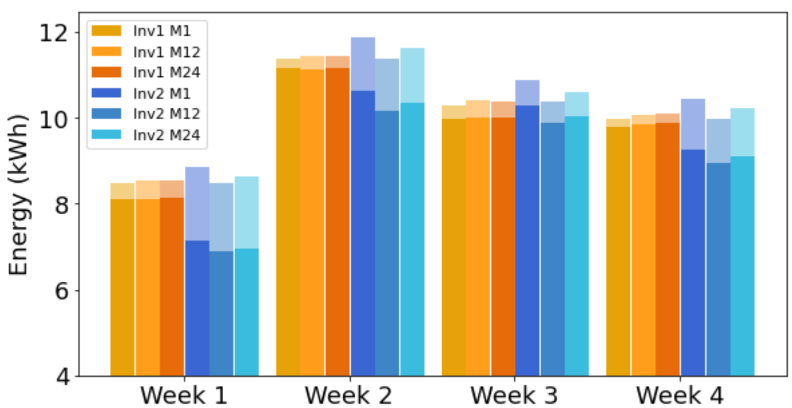

Figure 2: Yield difference in Pmp vs Pop

The difference in weekly yield from Operating power (Pop) vs. Potential power (Pmp) is shown in Figure 2. The lighter 'top' to each bar is the difference between what each module *could* have produced vs what it *did*. Inverter 1 was operating well with <3% difference between Pmp and Pop energy. Inverter 2 however had a >10% difference.

Deeper Analysis: Differentiating and Quantifying Losses

Morgan Solar tools are able to distill this data (quantify loss factors and distinguish between types of losses) to better inform mitigating actions. In Figure 3, losses were calculated for a module on string 2. In week 1, 1.06 kW is lost to inverter downtime, 0.383 kWh to clipping and 0.0561 kWh to inter-string mismatch.

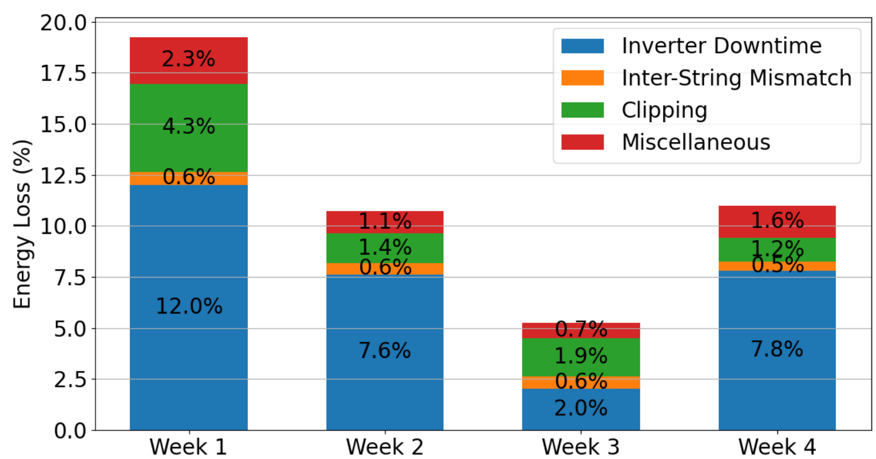

Figure 3: Energy Loss Breakdown

Unknown miscellaneous losses were reduced from 19.2% to 2.3% in week 1. Identifying loss factors enables quantification, analysis and more informed responses. Not all losses can be addressed, however understanding the discrete impacts between them enable more informed and cost effective responses.

Differentiation of Loss Factors

Measuring Pmp and Pop allows us to analyze these losses, as different types of losses result in different power plots over the course of the day. Here we show how capturing multiple IV curves over time (once every 15 minutes, or faster) allows us to discern between types of loss factors and assess the energy impacts of each.

Module Mismatch

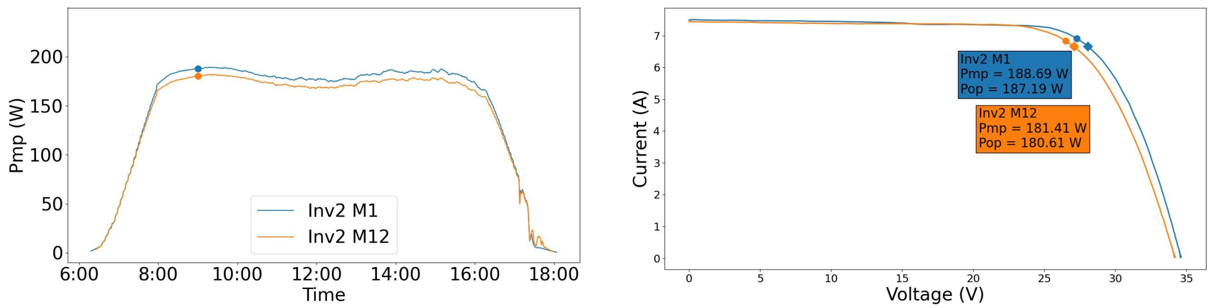

Figure 4: Example of Module to Module Variability

Distinguish between expected module-to-module variability and potential damage/shading affecting the modules: Shading issues may be captured in intra-string mismatching by analyzing IV curves for differences in voltages between two modules on string 2.

Inverter Analysis: Module Performance Impacts

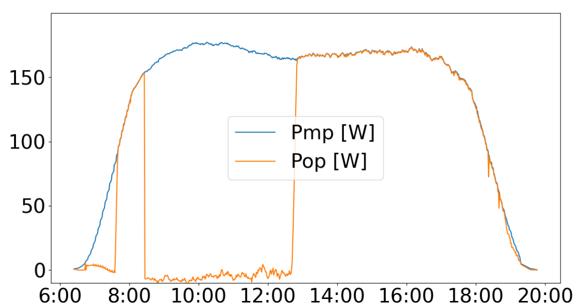

Figure 5: Inverter Downtime

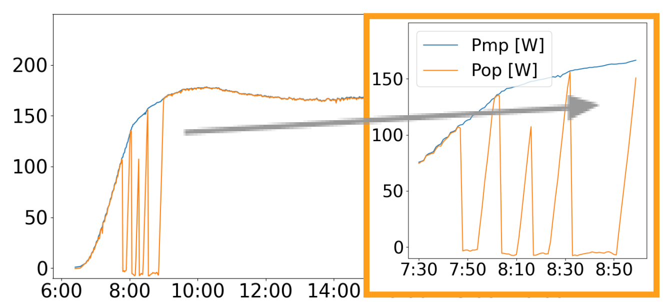

Figure 6: MPPT Tracking Issues

Quantify energy loss due to inverter downtime: Inverter down time is evident as a drop in Pop to zero when Pmp remains high.

Quantify energy loss due to MPPT tracking issues: This sawtooth shape is only observable in Pop, not Pmp, as the inverter tries to find the max power point but is unable to.

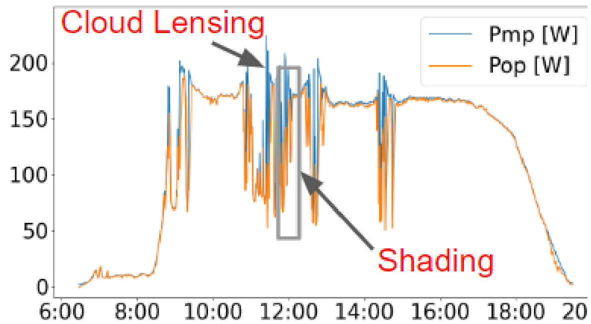

Figure 7: Effect of Cloud cover

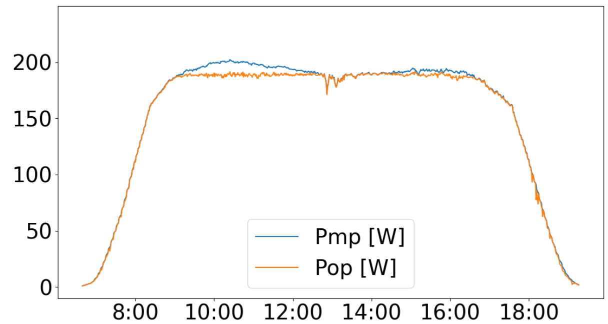

Figure 8: Example of Clipping

Evaluate ability of inverter to follow change in weather: Pop and Pmp follow each other well in events that impact irradiance such as cloud lensing and shading.

Quantify energy loss to inverter clipping: Pop reaches a ceiling corresponding to inverter peak rating but Pmp continues to increase.

4. Implications and Significance

Identifying loss factors and root causes enables both more informed and effective mitigating actions as well as improved modeling to account for them. This analysis enables us to quickly identify and troubleshoot factors impacting energy production. Recording both Pop and Pmp means that we can better isolate the effect of weather on solar farms, improving our ability to inform solar plant design.

Morgan Solar has built the world's largest weather-correlated IV curve database. As our database continues to grow, our analysis tools are also continually evolving to answer new questions and better inform both performance assessment and modeling.