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Comparative Review of High Resolution Monitoring Versus Standard Inverter Data Acquisition for a Single Photovoltaic Power Plant

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***Abstract*—Investing in data monitoring equipment will provide help ensure that the PV array is operating as expected. The systems can be designed to limit extensive downtime that would result in lost revenue. New, higher resolution systems can also be used to quantify performance using detailed characterization techniques. The Pordis 140A system can extract current and voltage (I-V) while the PV system remains connected to the grid. The added visibility for plant owners, investors, and operators is currently not well understood. Therefore, the present work provides an overview of the I-V tracing system in comparison to a typical, inverter data acquisition system for two systems located in Albuquerque, New Mexico. The review includes a description of basic energy yield calculations, degradation analysis, and abnormal behavior diagnostics.**

***Index Terms*—photovoltaic monitoring**

I. Introduction

Solar photovoltaic (PV) monitoring systems have been a valuable tool for owners, investors, installers, and operators to verify that plants are operating as expected [1]. This includes continuous, real-time monitoring and PV plant commissioning [2]. The design and installation of data monitoring systems includes a site survey, definition of monitored data and graphical interface, review of monitoring equipment power requirements, and specifications of data communications circuits. The intent has been to create a systems that helps avoid extensive downtime [3].

Typical PV systems have relied on maximum power point data acquisition (DAQ) systems instead of more advanced high resolution devices to monitor system health. The conventional monitoring systems have been used to sense DC and AC current, voltage, and maximum power. Where as, high resolution monitoring systems, available on the market today, can provide in situ current and voltage (I-V) curves. The high resolution monitoring does require more upfront investment and as of yet system owners have not jumped at the opportunity to install more advanced systems. The advantages of the in situ I-V curve tracing systems have not yet been clearly defined to help justify the investment.

The present work compares the output from an inverter DAQ system and an in situ string level I-V curve tracing device connected to two systems in Albuquerque, New Mexico. The evaluation of the typical and non-typical data monitoring approaches considered the review of energy yield, degradation, and characterization of abnormal performance. The system yield and performance ratio have been a convenient, yet elementary way to evaluate energy production of PV systems [4]. The analysis of degradation can be performed using power only [5][6], but I-V curves are required to define the specific degradation mechanism. The curves provide a detailed representation of system performance that can be used to quickly detect and diagnose abnormal system behavior.

II. Methodology

A. Photovoltaic Solar Array

The comparative analysis of high resolution and typical monitoring systems used two PV arrays located in Albuquerque, New Mexico (Figure 1). The first system was comprised of four strings labeled as 1A, 1B, 2A, and 2B as shown in Figure 2. The second system also had four strings

Fig. 1. The solar photovoltaic array was located in Albuquerque, New Mexico. It included two inverters that each supported four strings.

that were labeled as 3A, 3B, 4A, and 4B. The two systems had two different module manufactures and were connected to their own inverters that were the same make and model. The available ports in the inverters required that the A and B strings be combined prior to entering their respective inverters. The combination of the A and B strings for the two systems meant that the conventional monitoring system was not able to sense current and voltage at the string level.

B. Conventional Monitoring

The conventional monitoring system used in the present work was provided by the inverter manufacturer. The two SMA inverters were connected to a *cluster controller* device. The devices aggregated the data from each of the inverters and provided a visual interface and a ftp connection to collect performance data in xml or csv format. The *cluster controller*

provided time-series data in 5 minute intervals. The data was accessed each day by the research team and stored in the same database as the high resolution monitoring data.

C. High Resolution Monitoring

The Porids 140A high resolution monitoring system was used to collect string level I-V curves at 30 minute intervals for each string. The system was connected in-between the PV modules and the combiner box as shown in Figure 2. The 140A was designed as an in situ tracer, which means that it may remain connected to the array at all times without impacting normal operations. The I-V tracing process began with the

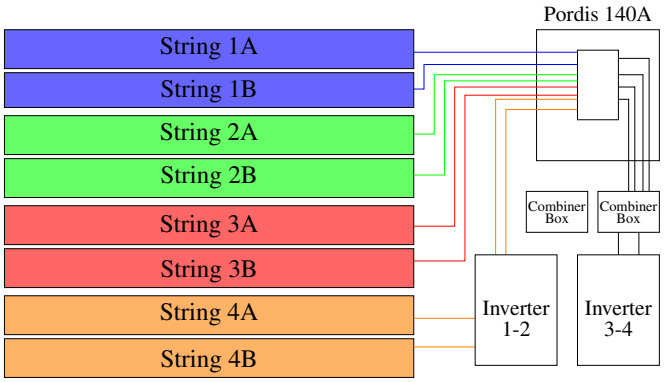

Fig. 2. The eight strings of the two test arrays connected to the Pordis I-V Characterization System and then to the combiner box before connecting to the inverter. Strings 1A, 1B, 2A, and 2B were comprised of modules that were different than 3A, 3B, 4A, and 4B strings.

isolation of a string from the array, the string was redirected to the load portion of the device, an I-V trace was performed, and then the string was switched back into the array. This process took about 100ms to complete. Additionally, the switch circuitry did not trip the high-frequency arc fault detection nor the ground fault detection of the inverter. The results from each of the string I-V traces were stored in a database located in the tracer system and were routed to the central database for analysis.

D. Comparative Analysis

The present work compared the outputs of a typical monitoring system provided by most inverter manufactures with a high resolution monitoring system that periodically performed I-V sweeps for each of the eight strings. The comparison included a review of the calculated energy yield, extent of the degradation analysis, and identification of abnormal behavior for each approach. Computing the daily, monthly, and annual energy production provides a high level evaluation of PV system performance. The degradation analysis provides plant owners and operators with a more detailed review of long-term system health.

The degradation analysis for the two monitoring approaches were slightly different. The typical monitoring approach evaluated the change in maximum power using the power performance index (PPI) [7]. The PPI was used to normalize the data by divided the measured power ($P_{measured}$) by the modeled power ($P_{modeled}$) output. $P_{modeled}$ was calculated using the California Energy Commission (CEC) model. The CEC model is based on the electrical representation of the PV module defined by the single diode equivalent circuit [8]. The final comparison discussed in the present work considered how the typical and high resolution approaches can be used to identify abnormal electrical performance.

III. Results

A. Energy Yield

The two approaches each measured the instantaneous maximum power. The conventional approach collected the maximum power as defined by the inverter controls. Whereas, the I-V tracing system discovered the theoretical maximum based on the measured I-V curve. The results for each approach over a two day period are shown in Figure 3. The accumulated

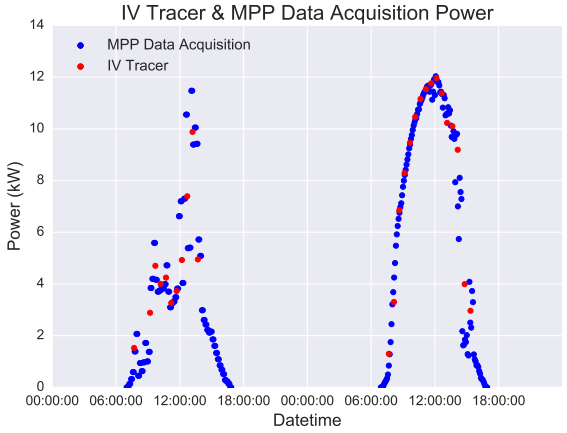

Fig. 3. The MPP data acquisition system collected data at 5 minute intervals and the I-V tracer performed sweeps every 30 minutes.

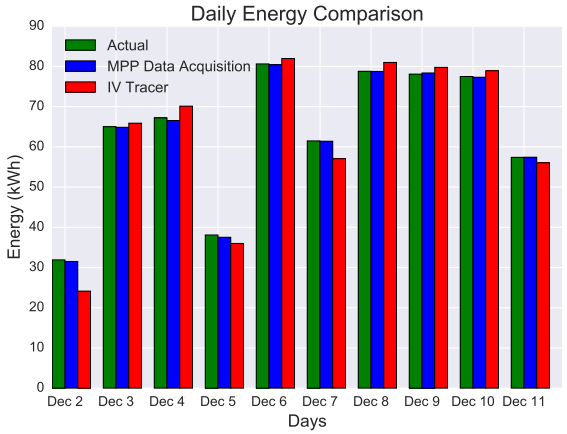

Fig. 4. The daily energy was computed using the two approaches and the MPP data acquisition system had smaller errors than the I-V tracing system.

energy for the I-V tracing system was not able to estimate the daily energy (Figure 4) as accurate as the conventional data acquisition system because of it measured the string power at a slower frequency.

B. Degradation

The degradation of the eight strings was evaluated using the data from the two monitoring systems. The typical approach

was only able to evaluate the degradation of the combined strings as shown in Figure 5. It was evident that the modules in strings 1A, 1B, 2A, and 2B performed differently than the modules in strings 3A, 3B, 4A, and 4B. The I-V tracing

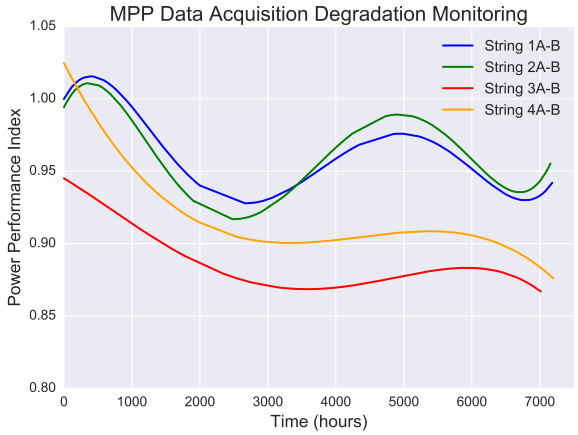

Fig. 5. Power performance index for the combined strings over a 42 week period showed that strings 3A-B and 4A-B degraded by about 10%. Strings 1A-B and 2A-B degradation was about 5%.

system, on the other hand, was able to characterize all of the strings. The system can be used to monitor short circuit and open circuit voltage changes over time as shown in Figure 6.

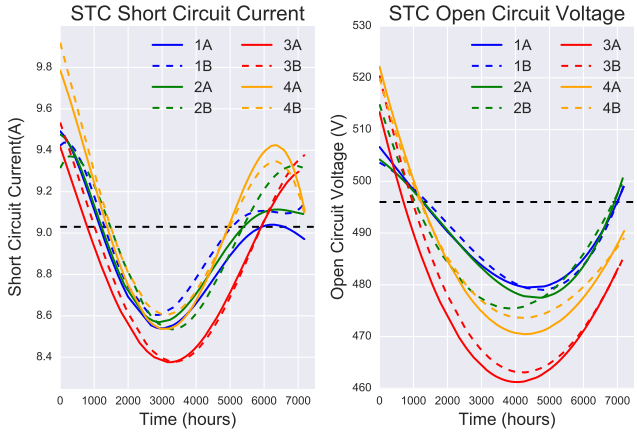

Fig. 6. The standard test condition short circuit current and open circuit voltage for each of the strings experienced a drop that reached a lows at different times. The current and voltage then rebounded back towards the name plate values.

C. Abnormal Performance

Any abnormal sub-system performance was difficult to identify using inverter level monitoring. For example, end of the day shading caused by low sun angle and nearby fences was not clear in the DC power as shown in the left side of Figure 7. The string level mismatch was evident in the I-V curves as shown in the right side of Figure 7.

IV. Conclusion

The present work compared the outputs of conventional monitoring with a high resolution system. Yet, the results showed some similarities but the high resolution offers features that allow analysts to understand degradation and abnormal

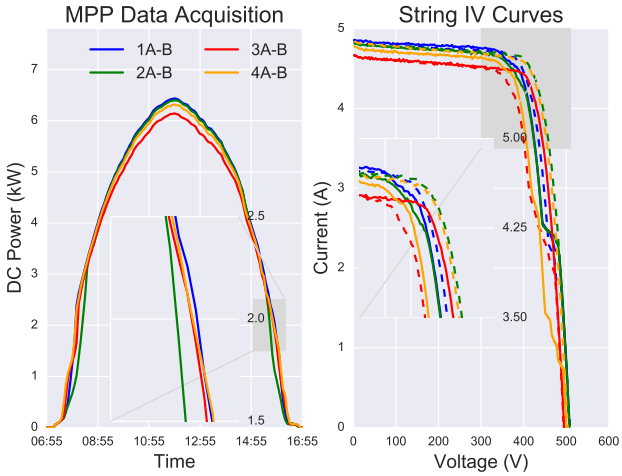

Fig. 7. The end of the day shading was difficult to notice in the maximum power point data provided by the inverter. It was clear in the string level I-V curves.

behavior in more detail that could lead to improved decision making.

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