Validation of Inverter Labeling with Plant Transfer Functions

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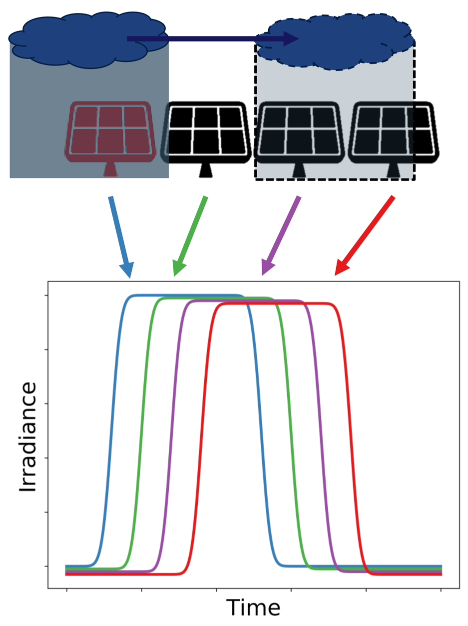
Introduction

Operators of PV plants deal with extremely large quantities of monitoring data at a sub-plant level (combiners or inverters). Concern about labeling mistakes during the plant commissioning could cause uncertainty about the veracity of measurements and reduces confidence and usefulness of the data. Manual verification would require time and cost intensive site inspections. Analysis methods that can validate plant labeling would reduce the cost of auditing and correcting these mistakes and improve plant profitability. This study investigates whether existing tools can be applied to validate segment level labeling within a hypothetical PV plant.

The Cloud Advection Model describes plant aggregate output

The Cloud Advection Model (CAM) is a model related to spatial aggregation of irradiance and is based upon analysis of frozen clouds that pass across a plant over time. Given a spatially distributed plant and a reference irradiance time series, the model predicts the transfer function representing the mapping between the reference and the aggregate plant. In this study, these transfer function predictions are used to discriminate between different segments of the plant.

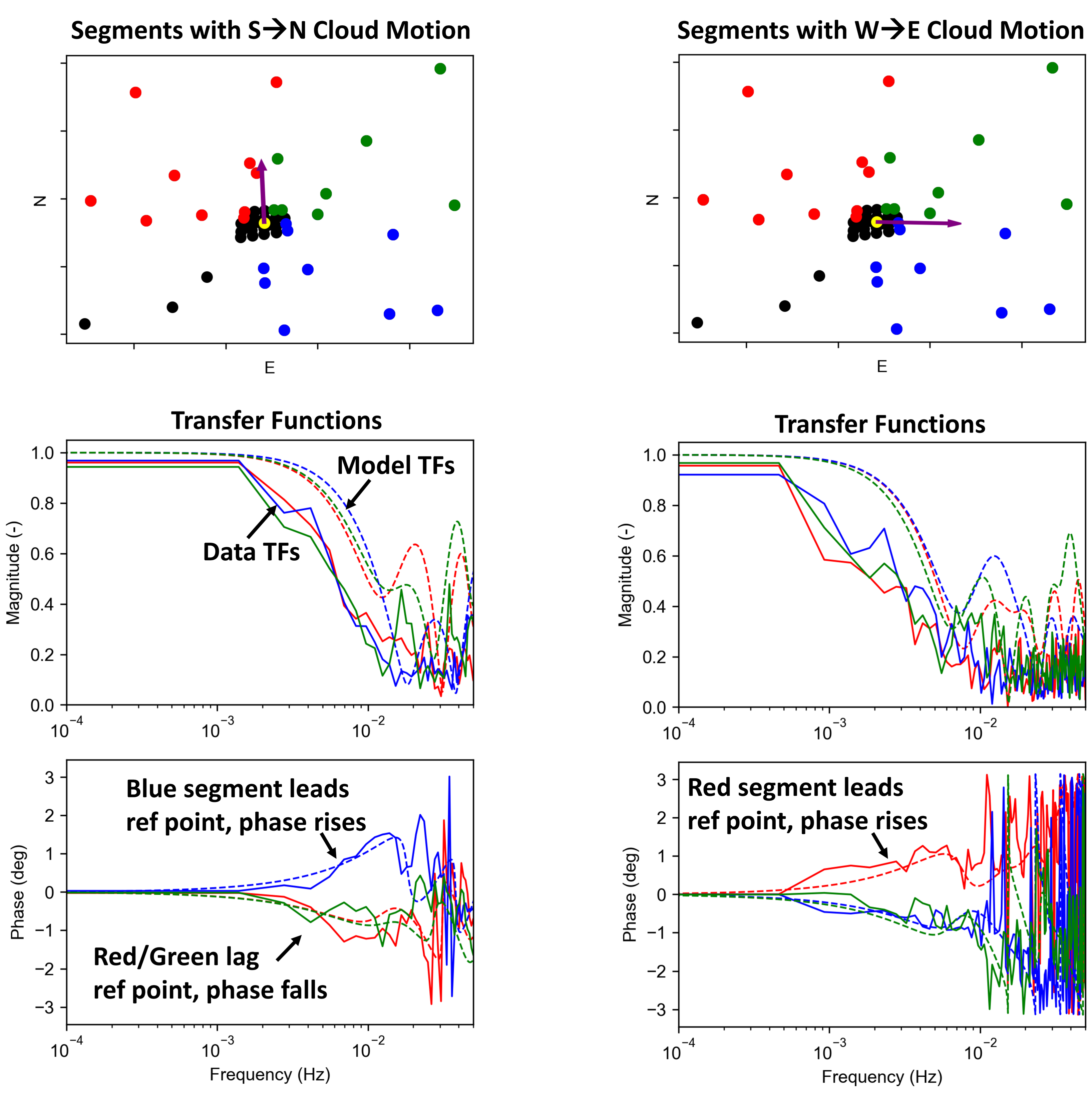


$$TF(f) = \frac{P(f)}{G_{ref}(f)} = \mathcal{F}(d)$$

The transfer function between the reference site and the plant is the Fourier Transform of the spatial distribution.

The approach was tested on simulated plant segments

Real plant data output data was not available, so plant segments were simulated using subsets of a spatially distributed irradiance measurement network. Segments were selected with varying position relative to the cloud motion. Transfer functions were computed between the central reference and each segment, to look for features that could be used to discriminate between the segments. The two-dimensional nature of the segment layout requires that cloud motion vectors span the plane. Two different cases were selected with cloud motion in perpendicular directions and transfer functions were compared for the model and the real data.

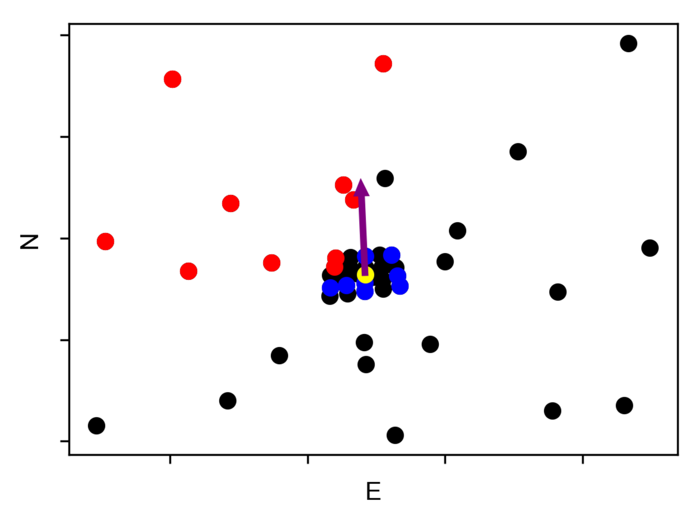


Transfer function phase is the best tool for identification

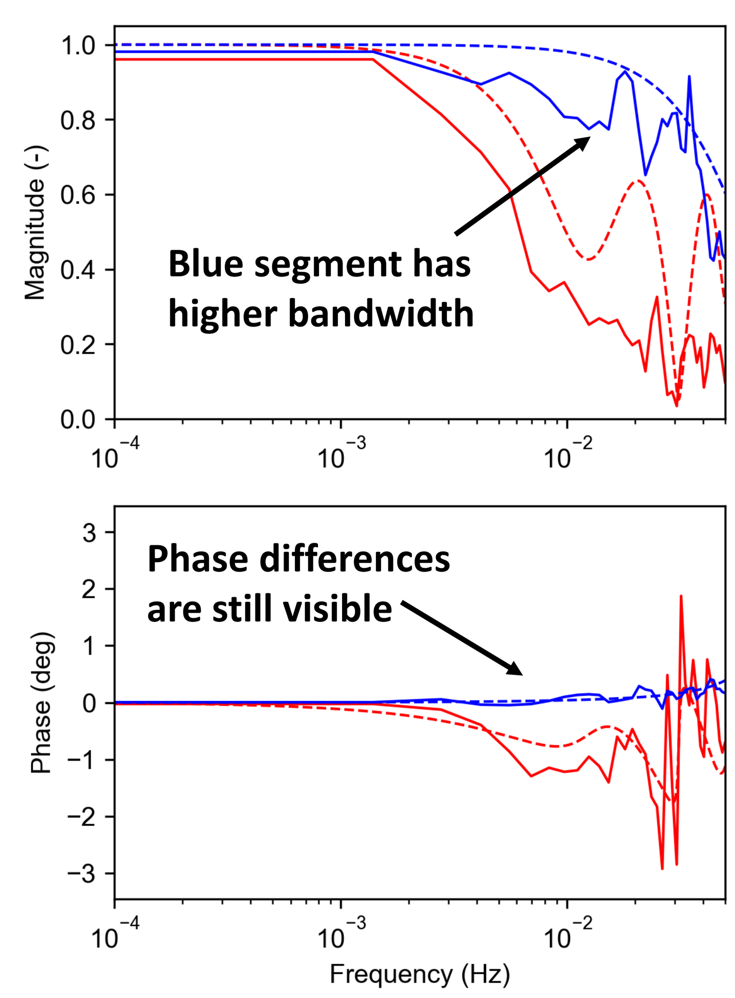
The low-frequency phase of the transfer function is primarily shaped by advective time delay between the reference point and the geometric center of the segment. Clouds reach the reference and the segment at different times, causing segments to exhibit lead or lag in the phase based on their position. Good agreement is observed between the model and data at low frequencies, including both the time delay and initial dynamic characteristics. By predicting the expected lead or lag of each segment using the model, and checking for a match with the actual data, the ability to discriminate between segments is demonstrated. The necessity of multiple cloud motion directions can be seen when considering two segments that are co-located with respect to the cloud motion direction. The similarity in predicted phase for co-located segments requires the second cloud motion vector, which has the effect of separating the position of the two segments in the new direction, and regaining the ability to discriminate between segments.

Transfer function magnitude is similar for similar segments

Generally, predictions of the transfer function magnitude show the expected low-pass filter shape. Because the segments considered in previously have similar spatial extents relative to the cloud motion, the overall shape of the magnitude predictions is very similar. Since most large-scale PV plants are made up of regularly spaced segments, it is likely that magnitude predictions would be too similar to be useful in discriminating segments. However, to develop better understanding of the approach, a case with non-uniform segment shape was tested. When the plant shape is substantially different in the cloud motion direction, magnitude changes can be observed, especially as it concerns the bandwidth. Segments with a smaller footprint in the cloud motion direction would be predicted to have a higher transfer function bandwidth, which agrees between the data and the model, as in the figure.



The blue segment was chosen to demonstrate a much shorter footprint in the cloud motion direction as compared to the red.



Conclusion

This study simulated an approach for differentiating segments within a distributed PV plant using transfer functions. The computed transfer functions allowed the plant segments to be differentiated using multiple features. Primarily, this occurred by observing different values for time delay in the phase for plant segments located up- or downwind in the cloud motion direction. Transfer function magnitude also could be used, but only when segments had significantly different sizes/shapes in the cloud motion direction. Though the approach showed promise, this study used irradiance network measurements to simulate a plant, as opposed to real data. The application should be studied on actual PV plant data to determine the practical usefulness of this technique.

Acknowledgments

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