Developer Response to Present Utility Voltage Fluctuation Analysis

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  - Analyzing Real World Fluctuation Data
  - Geographic Smoothing
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- IEEE 1453: Proven Credibility in Dynamic Analysis
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  - Xcel Minnesota and Implementation of IEEE 1453
- Conclusions

Introduction

Focus of Presentation

- Visible Flicker as opposed to Voltage Variation
  - Impact on regulation devices
- Recommendation is to use Dynamic Analysis
  - Long-term dynamic modules
  - Realistic levels of ramping
  - Account for geographic diversity between systems
- Recommendation is consistent with 2013 report from Sandia National Laboratory
  - “Time Series Power Flow Analysis for Distribution Connect PV Generation”
  - Robert J. Broderick, Jimmy E. Quiroz, Matthew J. Reno, Abraham Ellis, Jeff Smith, and Roger Dugan
  - Sandia National Laboratories, January 2014 (SAND2013-0537) p. 18

Introduction

Why should the JU's approach to visible flicker change?

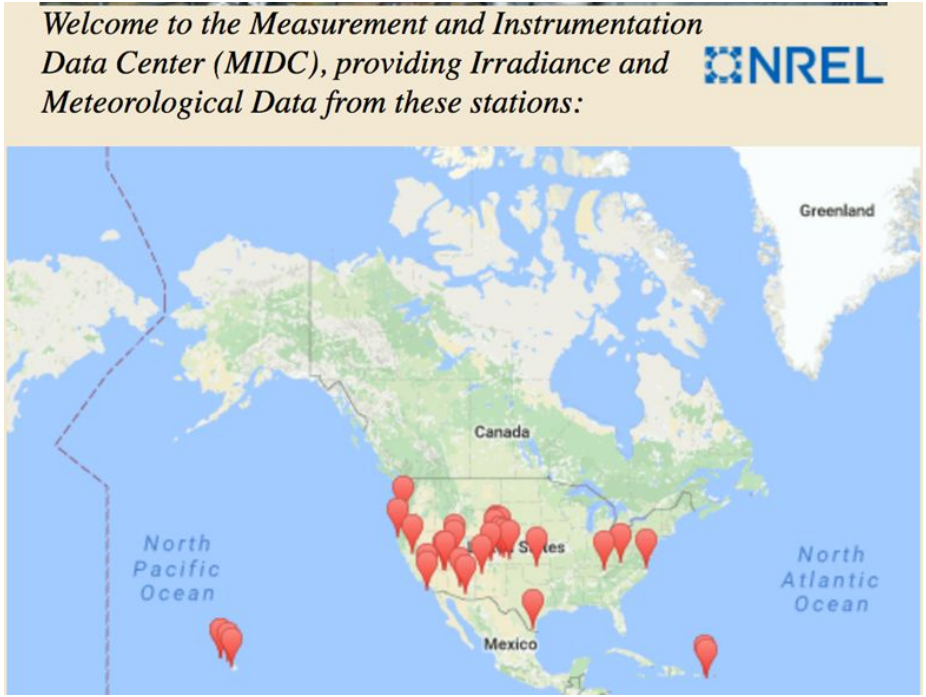
1. Due to extensive experience with systems in the real world as well as analyses of solar irradiance data, the solar industry believes that it is very unlikely that visible flicker (i.e. the impact of voltage variation on lighting) will be a concern for solar PV installations.
2. In 2014, the latest version of IEEE 519 removed any reference to the so-called Flicker Curves in their entirety. Thus, the previous version of IEEE 519-1992 (now nearly 25 year old) was officially superseded leaving the methodology in IEEE 1453 as the only active IEEE standard for flicker.
3. In addition, the adoption of limits based on the IEEE 1453 methodology are also likely to be included in the revised power quality section of IEEE P1547 currently under consideration.

Thus, the solar industry argues that there is no longer an active IEEE 519 flicker standard to apply, and references to it should be eliminated.

A Priori Flicker Analysis is Unlikely to be Needed

Priori Flicker Analyses are Unlikely to be Needed

Examining Real Data: Is visible flicker caused by PV generators?



- Data on solar irradiance over multiple years is available from NREL MIDC at three locations in the eastern US.
- Two data sets are at a five minute resolution while one (Oak Ridge National Lab) is available with one minute resolution.

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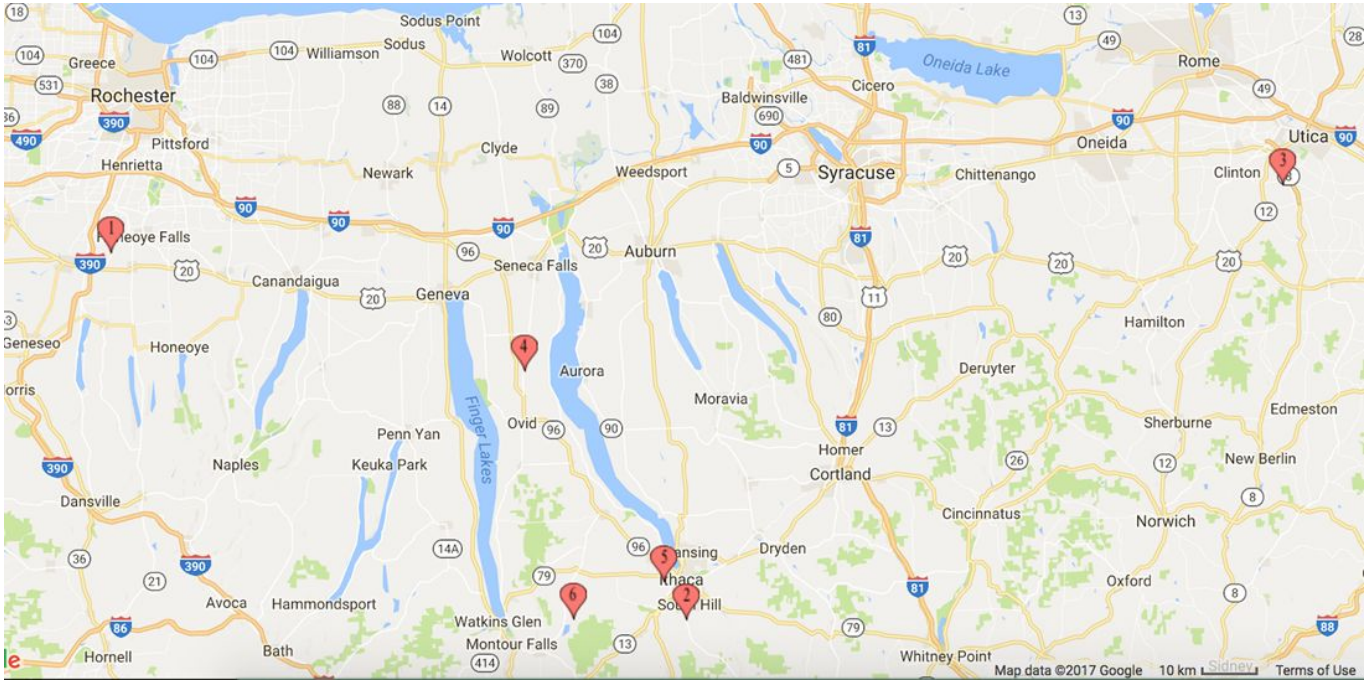
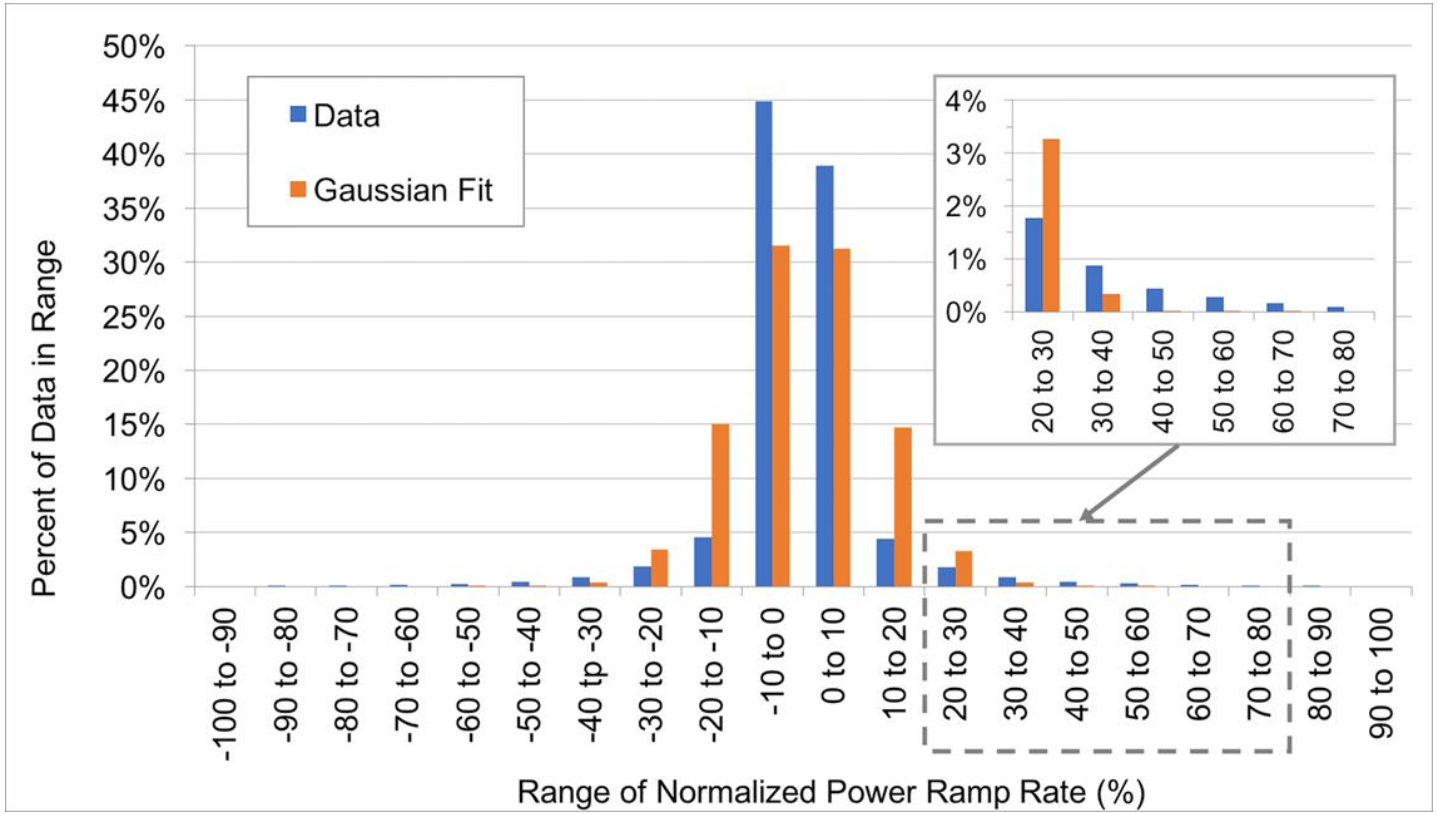


Production data from residential ground-mounted solar arrays at a five minute resolution is also available from 6 sites across central New York

Priori Flicker Analyses are Unlikely to be Needed

Examining Real Data: Normalized Power Fluctuations in NY (2013 & 2015)



Priori Flicker Analyses are Unlikely to be Needed

Examining Real Data: Normalized Power Fluctuations in NY (2013 & 2015)

- For the largest of the New York arrays studied (35 kW) the largest ramp rate over five minutes observed in either year was 65%

- For all six arrays, the 99th percentile fluctuation between 8am and 8pm was 50% after adjusting data for a DC to AC ratio of 1.3

- Variability over shorter time-frames (such as 1 minute) would be smaller than these 5 minute measurements

Priori Flicker Analyses are Unlikely to be Needed

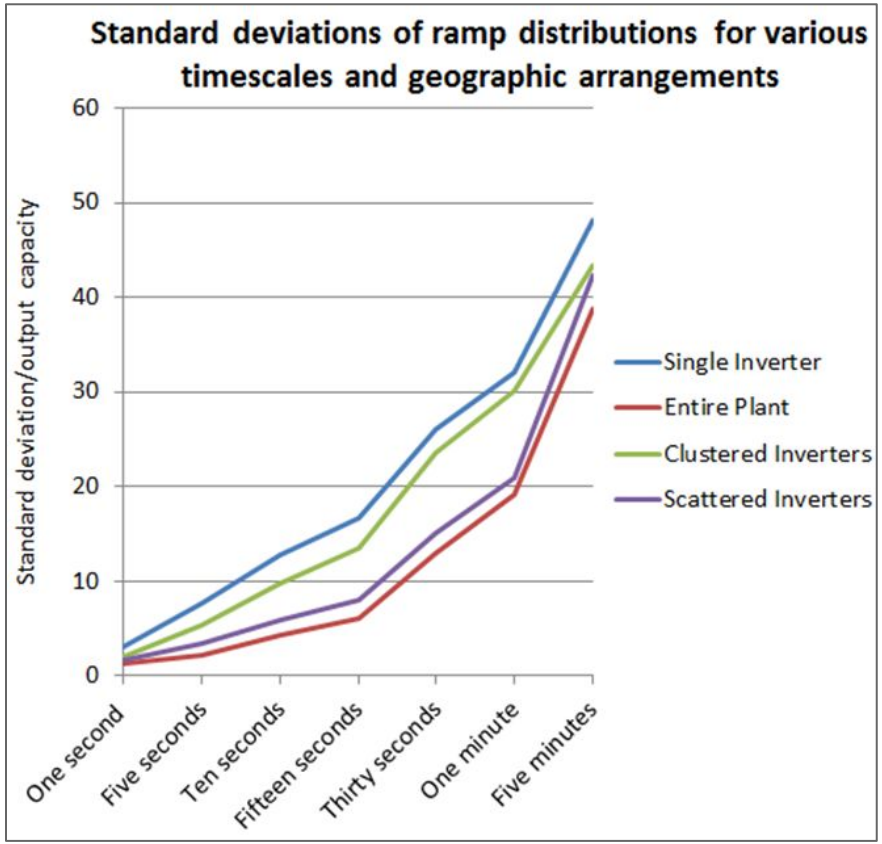
Examining Real Data: Normalized Power Fluctuations at NREL MIDC Stations Conclusions

- No instances of fluctuations in normalized irradiance greater than 90% were found for any of the MIDC sensors at…
  - Oak Ridge (nine years of data)
  - Elizabeth City state University (six years of data)
  - Bluefield College (seven years of data)

- At a resolution of one minute there were just **10 total instances** of fluctuations between 80% and 90% **out of more than 2.37 million** data points from the Oak Ridge RSR (i.e. 0.0004%).

Priori Flicker Analyses are Unlikely to be Needed

Examining Real Data: Geographic Smoothing of Power Ramp Rates

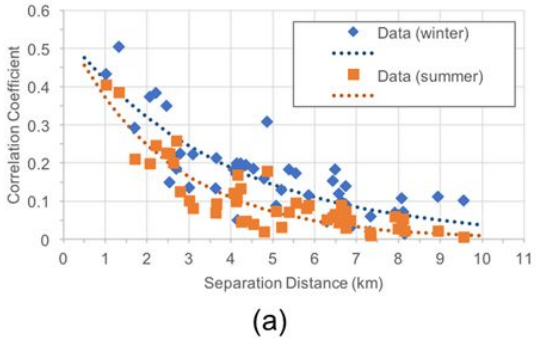


- The NREL data are single point irradiance measurements. For real systems the geographic smoothing over MW scale arrays will further reduce the actual fluctuation in output.
- Geographic smoothing between different arrays will be even more dramatic arguing against the 100% to 0% transition for all PV on a circuit or even for all PV within a 3 km radius as is done by some New York utilities.

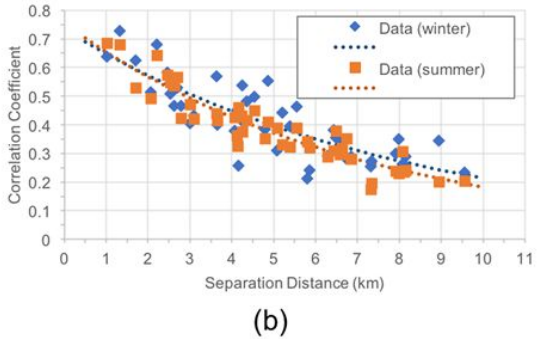
Shedd, S., Hodge, B., Florita, A., Orwig, K., 2012. A Statistical Characterization of Solar Photovoltaic Power Variability at Small Timescales. 2nd Annula International Workshop on Inegration of Solar Power into Power Systems Conference, Lisbon, Portugal.

Priori Flicker Analyses are Unlikely to be Needed

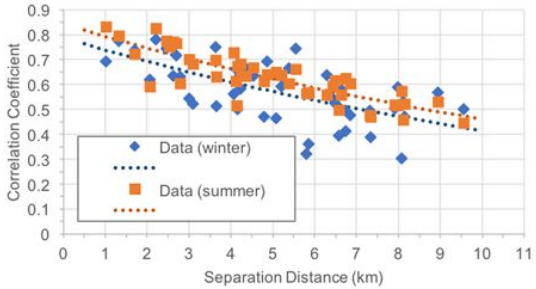
Examining Real Data: Geographic Smoothing of Power Ramp Rates



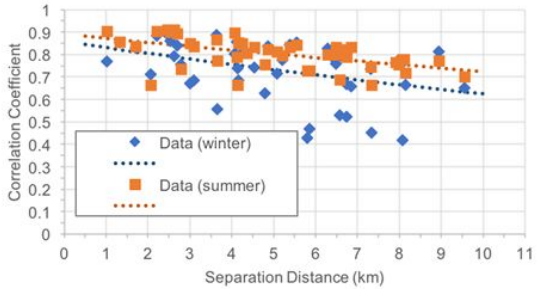
(a)



(b)



(c)

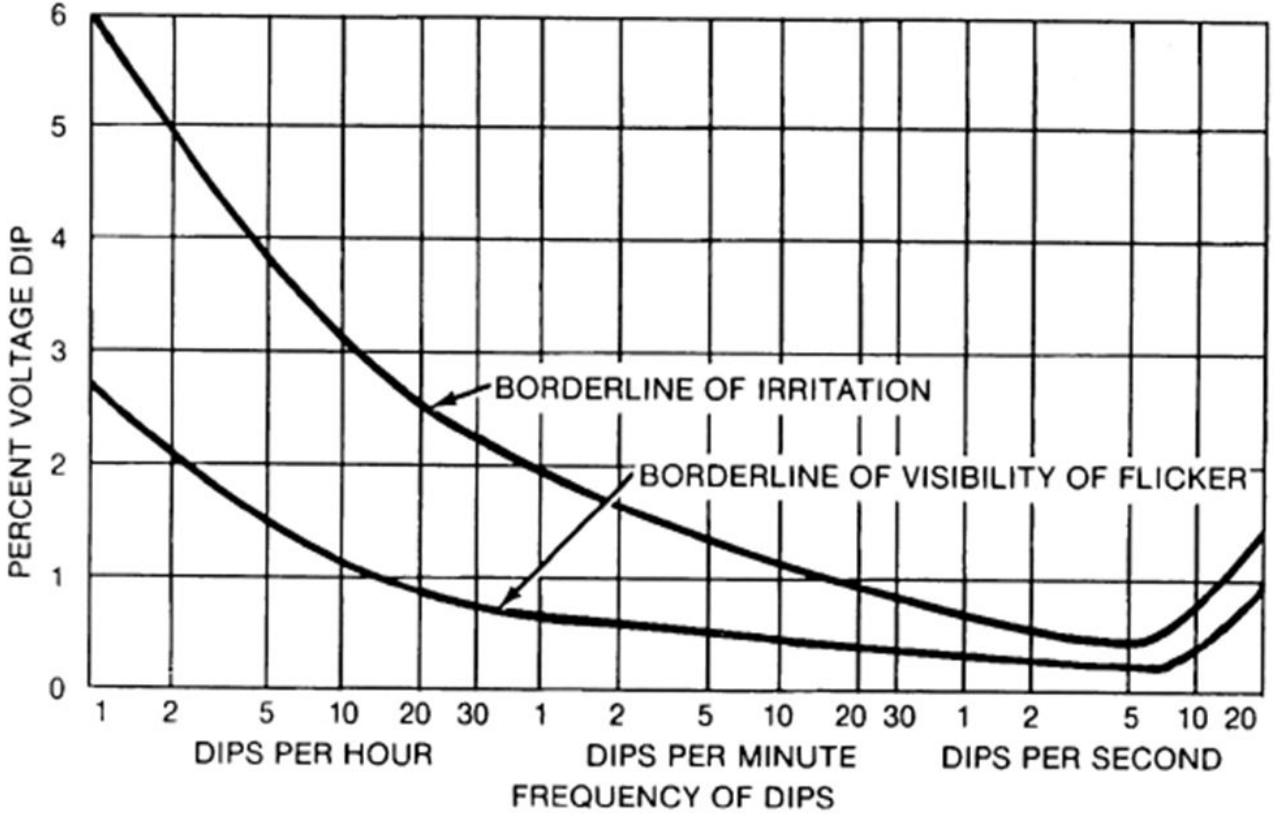


(d)

- Correlation in power ramp rates for 47 pairs of residential systems in Central New York between 1 and 10 km apart
- By 500 meters the correlations at five minutes drop below 0.5

Priori Flicker Analyses are Unlikely to be Needed

Even outdated IEEE-519 shows that flicker issues are unlikely



Priori Flicker Analyses are Unlikely to be Needed

Even outdated IEEE-519 shows that flicker issues are unlikely

Data Source	Resolution	99th Percentile Fluctuation (8am to 8pm)	Effective ΔV/V Limit for 100% to 0% Transition
Oak Ridge (nine years of data)	1 minute	38%	2% / 0.38 = 5.3%
CNY Residential Ground Mounted Arrays (adjusted for DC to AC ratio of 1.3)	5 minute	50%	3% / 0.50 = 6.0%
Elizabeth City State University (six years of data)	5 minute	43%	3% / 0.43 = 7.0%
Bluefield College (seven years of data)	5 minute	43%	3% / 0.43 = 7.0%

IEEE 519-1992: Outdated and Inappropriate for Solar PV

IEEE 519-1992: Outdated and Inappropriate

IEEE 1453 and the GE curves

- IEEE 1453 itself acknowledges the inappropriateness of using the GE flicker curves for non-regular, non-square wave changes in load. The same considerations hold for changes in generation produced by solar farms under transient cloud cover.

- "The [GE flicker] curves were developed based on standard rectangular modulations of the 60-Hz sine wave. Such curves are suitable for step changes in RMS voltages, but are not suitable for predicting flicker caused by other sources like arc furnaces, which are random in nature and have irregular wave shapes."
  - IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems, IEEE 1453-2015 (p. 6)

IEEE 519-1992: Outdated and Inappropriate

Sandia National Laboratory Study of Conducting Time-Series Analysis for Flicker

- "The disadvantage of using the older IEEE 519 flicker curves for evaluating the voltage variation caused by PV is twofold. First, the flicker curve requires knowledge of not only the percent voltage dip caused by variation in PV plant output but also the frequency of the voltage dip…. The second problem is the design of the flicker curve which was developed to address fast voltage changes such as motor starts and not the slowly changing voltage variation seen with PV. These problems with the IEEE 519 flicker curves often lead to an unnecessarily conservative approach for determining PV induced flicker impact. "
  - "*Time Series Power Flow Analysis for Distribution Connected PV Generation*"
  - Robert J. Broderick, Jimmy E. Quiroz, Matthew J. Reno, Abraham Ellis, Jeff Smith, and Roger Dugan
  - Sandia National Laboratories, January 2013 (SAND2013-0537) p. 45

IEEE 519-1992: Outdated and Inappropriate

Sandia National Laboratory Study of Conducting Time-Series Analysis for Flicker

- "The report demonstrates how new methods and tools can be used to assess the potential impacts in a more comprehensive manner than the typical simulation tools and snap shot methods in use today. Because PV output is highly variable, the potential interaction with control systems is not adequately analyzed with traditional snapshot tools and methods that only provide an assessment of the distribution system at one instant in time."
  - "*Time Series Power Flow Analysis for Distribution Connected PV Generation*"
  - Robert J. Broderick, Jimmy E. Quiroz, Matthew J. Reno, Abraham Ellis, Jeff Smith, and Roger Dugan
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IEEE 519-1992: Outdated and Inappropriate

Sandia National Laboratory Study of Conducting Time-Series Analysis for Flicker

- To illustrate this point, the Sandia report highlights a model circuit that was electrically weak and had a PV plant that was sized to 100% of the feeder's peak load and 240% of the feeder's minimum load.
- The largest ramp-rate occurred over a 5 minute period with a voltage dip of 2.65% at the PCC. However, the Pst for this event was 0.07 which was far below the planning level of 0.9.
- The report went on to conclude that "[t]his shows that the flicker associated with the largest delta V ramp, was not a problem for this feeder" and that "[n]one of the Pst exceeded the planning level of 0.9 and none of the Plt approached the planning level of 0.7."
  - "*Time Series Power Flow Analysis for Distribution Connected PV Generation*"
  - Robert J. Broderick, Jimmy E. Quiroz, Matthew J. Reno, Abraham Ellis, Jeff Smith, and Roger Dugan
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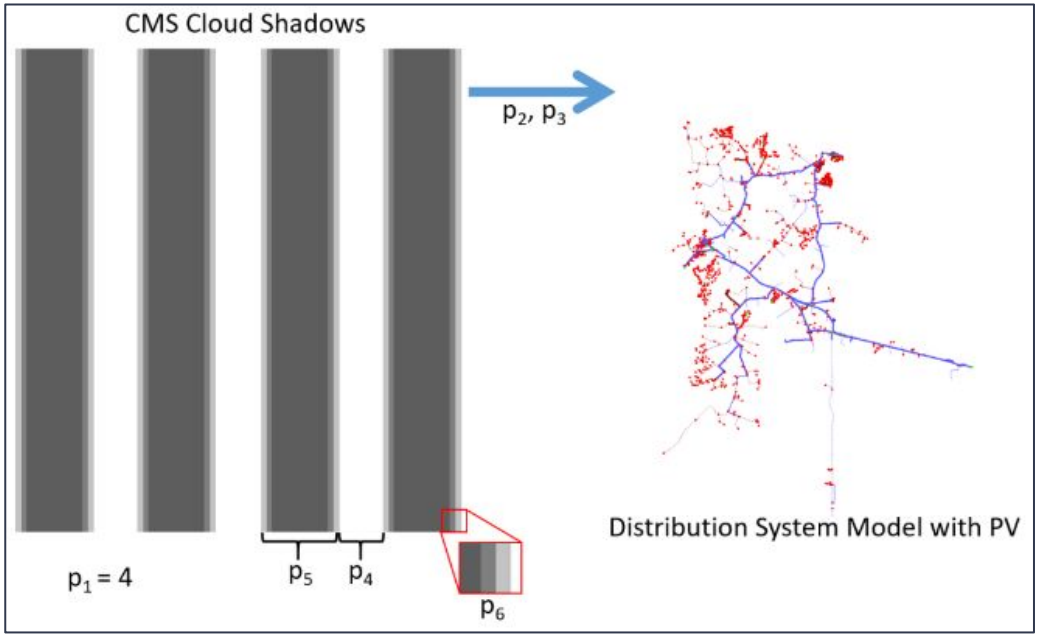
Cloud Motion Simulation

Implementing IEEE 1453 and Geospatial Smoothing in Electrical Distribution Design's Software

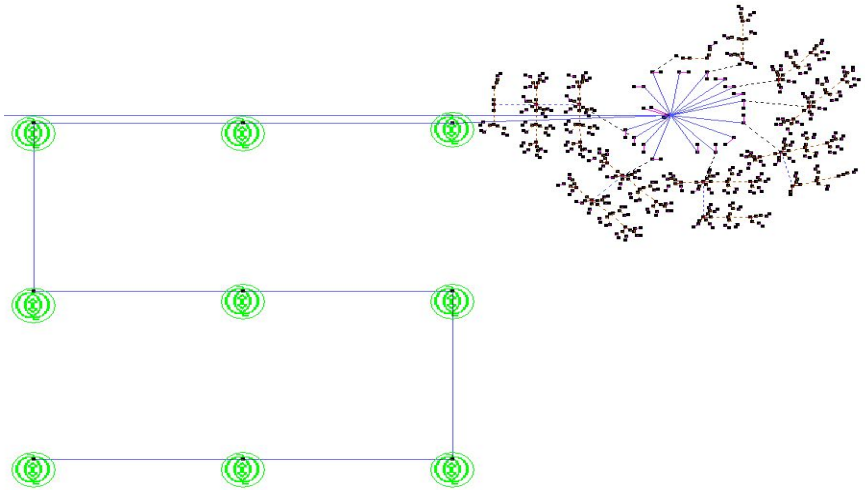


P1 = Number of clouds per unit time
P2 = Direction of cloud motion
P3 = Speed of cloud shadows
P4 = Time between successive clouds
P5 = Width of clouds
P6 = Decay of PV generation

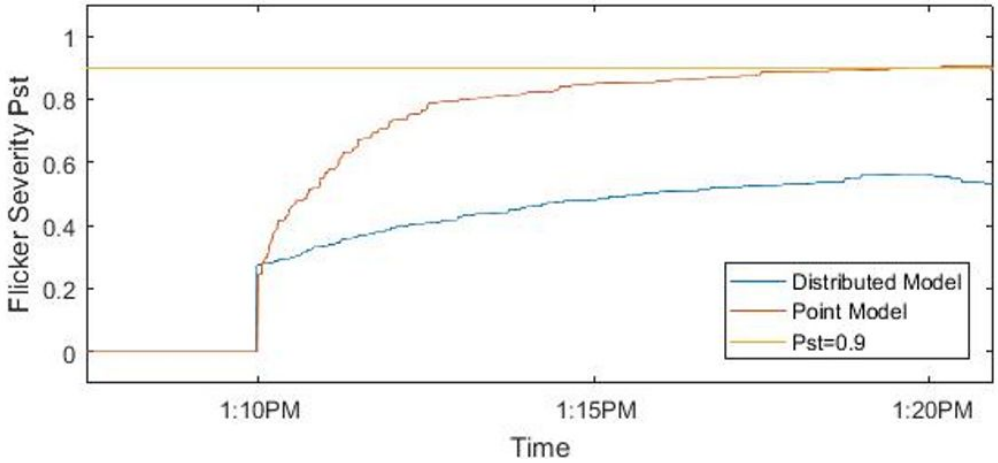
Results courtesy of Electrical Distribution Design, Inc.

Cloud Motion Simulation

Evaluating 6.3 MW of PV Covering 38 Acres



Four clouds (eight changes) per minute. Two times more conservative than the JU average.



Results courtesy of Electrical Distribution Design, Inc.

Cloud Motion Simulation

Using IEEE 1453 and a distributed model results in significantly higher penetrations.

Flicker Curve

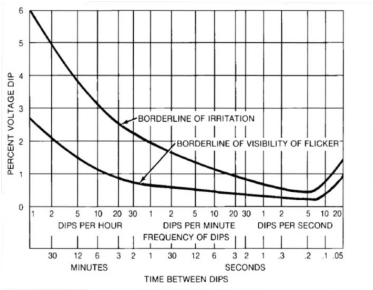


Image Source: IEEE

716 kW

Flickermeter

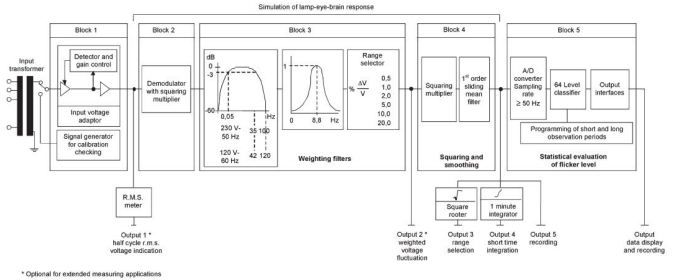


Image Source: IEEE

6.3 MW

Results courtesy of Electrical Distribution Design, Inc.

Cloud Motion Simulation

Key Findings

“Using the IEEE 1453-2015 flickermeter resulted in significantly higher flicker-limited allowable PV penetration levels than using the obsolete flicker curves from IEEE 519-1992.”

“However, a PV Penetration Ratio of [500%] is likely unattainable due to other limiting factors outside the scope of this paper...”

“Comparison of Voltage Flicker Analysis Approaches to Maximum PV Penetration Levels.” Electrical Distribution Design, Inc. (2017)

Results courtesy of Electrical Distribution Design, Inc.

IEEE 1453:
Proven Credibility in Dynamic Analysis

IEEE 1453: Proven Credibility in Dynamic Analysis

Use of IEEE 1453 by Utilities for Variable Loads

- **2006** – Alabama Power Company
- Took a first meaningful step towards adopting IEEE 1453 via use of flickermeter measurements from similar loads
- "The use of the recommended flicker limits provided within IEEE 1453 for electrical system design does yield workable results. In using the GE Curve, an engineer wants to make sure that the final system design will be free of flicker complaints. **The experience thus far using the IEC recommended limits, as included in IEEE 1453, has provided similar results. This has been accomplished with basically the same analytical tools used with the old method.** The only addition is a means of converting calculated voltage drops to Pst values."
  - "*IEEE 1453 – How Well Does it Work in the Real World*"
  - Power Engineering Society General Meeting, 2006. IEEE
  - Reuben F. Burch IV

IEEE 1453: Proven Credibility in Dynamic Analysis

Use of IEEE 1453 by Utilities for Variable Loads

- **2007** – PacifiCorp
- Took a meaningful step towards adoption of IEEE 1453 via use of the Electrical Pollution Screening (EPS) tool
- "**Flicker approaches have been stuck in an uncomfortable rut for many years in North America. The walls of this rut have been formed by the belief that all fluctuating loads could be molded into constant period, constant magnitude fluctuations. Today it is recognized that many loads do not fit this mold. Indeed, this has been the case for decades.** We are indebted to the IEC and its supporting organizations for leading out in its 61000-4-15 standard to light the way for the IEEE 1453 standard. **Now that these standards have defined a better approach to flicker we should move to it as quickly as we can, keeping in mind the human element as we do.**"
  - "*PacifiCorp's Application of IEEE 1453*"
  - Dennis Hansen
  - Power Engineering Society General Meeting, 2007. IEEE

IEEE 1453: Proven Credibility in Dynamic Analysis

Use of IEEE 1453 by Utilities for Variable Loads

- **2007** – Alabama Power Company
- Took a second meaningful step towards IEEE 1453 by use of shape factors for the variable load
- "**The use of IEEE 1453-2004 as a means of determining flicker compliance can be accomplished using existing analysis methods and tools with a minimum of additional work.** The necessary additional tools are available and can be mastered in a reasonable amount of time. The benefits of adopting this method are many."
- Among the benefits, the author noted that "the use of this method typically allows us to serve loads which we have either denied when using the GE curve or served by installing or having the customer to install mitigation equipment that might not have been required" and that **"this method more accurately predicts the resulting flicker since it was designed to work with all load shapes, not just periodic square waves."**
  - "*Using IEEE 1453 Limits to Determine Flicker Compliance - How Does it Compare to Using the GE Curve*"
  - Reuben F. Burch IV
  - Power Engineering Society General Meeting, 2007. IEEE

IEEE 1453: Proven Credibility in Dynamic Analysis

Use of IEEE 1453 in Academic Studies

- **2009** – Electricite de France and Electricite Reseau Distribution France
- "For flicker assessment in the sophisticate network and with irregular load changes, the method based on electric circuit simulation including flicker source models and IEC flicker meter emulator is presented. Case studies show this method is very appropriate in pre-connection studies."
- "**For sophisticate case studies, the recommended method is to perform grid simulation with IEC flicker meter emulators and flicker load models.** The grid can be modeled by an equivalent fictitious model or directly by accessing system operator's database. A flicker meter emulator is recommended in power quality software. **Flicker meter method can make acceptable flicker assessment of any fluctuating installations to connect to the grid."**
  - "*How can flicker level be determined before a customer is connected to the electric grid*"
  - X. Yang and J. Gauthier
  - Power & Energy Society General Meeting, 2009. PES '09. IEEE

IEEE 1453: Proven Credibility in Dynamic Analysis

Use of IEEE 1453 by Utilities for Solar DG

- **2014** – National Grid, Massachusetts
- "The IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems, IEEE Std. 1453-2004 provides guidance on flicker and voltage fluctuations."
- "In addition to steady state analysis, a long term dynamic analysis (6 hour- 10:00AM - 4:00PM) was run using EPRI supplied generation data from National Grid's Haverhill, MA PV for October, 16, 2012, (Partly Cloudy day) and 6 hr feeder load curves for peak loading at time of peak generation and minimum loading at time of peak generation."
  - *System Impact Study For MA-17322373 Town of Chelmsford 40 Swain Rd, Chelmsford, MA 01824*
  - 750 kW Three-Phase, Inverter Based Photovoltaic Generation
  - Interconnection to National Grid's 13.2 kV System, 12/5/2014 (p. 10-11)

IEEE 1453: Proven Credibility in Dynamic Analysis

Use of IEEE 1453 by Utilities for Solar DG

- **2016** – Minnesota Independent Engineer
- "In this decision, the IE cites the Sandia-EPRI report and benchmarks three large North American entities comparable to Xcel Energy. **All three entities use the IEEE Standard 1453-2015 to evaluate the impact of flicker on the distribution system.** The IE also references a Case Study that demonstrates the effectiveness of using IEEE Standard 1453. **The IE finds that Xcel Energy should be using IEEE Standard 1453 in the evaluation of flicker impact on the distribution system with the interconnection of DER."**
- "The IE finds that Xcel Energy's use of the IEEE Standard 141 [i.e. the GE flicker curves] does not accurately evaluate the grid impact of flicker related to the interconnection of DER."
  - Independent Engineer Decision, Community Solar Interconnection Engineering Dispute Between Xcel Energy and SEV MN1 LLC Seeking to Interconnect with Xcel Energy's Distribution System in Minnesota. Decision Resolving Solar Garden dispute with Xcel Energy, Date September 2, 2016 p. 1-2, 16

IEEE 1453: Xcel's Implementation of in Minnesota

Technical Workshops on IEEE 1453 Solar Implications

Study	PV/DG Facilities	Study Locations	Output Change	Threshold
Single DG Facility (RVC)	Individual Facility	All Feeder Nodes	100%->0%	3%
All Feeder DG Facilities (RVC)	All Facilities on Circuit	All Feeder Nodes	100%->0%	5%
Voltage Fluctuation at Voltage Regulation Devices	Individual Facility	Voltage Regulator Nodes	100%->25%	1.5%*

*effectively 2% for change from 100% to 0%.

- Decouples voltage flicker from voltage regulator tap changes.
- Recognizes geospatial smoothing between individual facilities. Should be updated to recognize geospatial smoothing within individual facility.
- The use of rapid voltage change does not match the latest guidance in IEEE P1547. This practice will need to be revised when the new standard is in effect.

Conclusions

Conclusions

- Based on multiple lines of analyses, the solar industry believes that it is extremely unlikely that visible flicker presents a concern for solar PV installations that justifies the effort and complexity involved with conducting an accurate time domain analysis and is better addressed via changes to the interconnection contract and a post facto measurement process.

- However, if our recommendations to eliminate the a priori study of visible flicker within the Supplemental Review and CESIR processes are not adopted, then the solar industry would strongly oppose the application of any standard or analysis methodology other than IEEE 1453 which has been demonstrated to be both practical and effective for the study of variable loads/generation.

Questions?