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History of Flicker Discussions at the New York State Interconnection Technical Working Group

By Shay Banton

AGENDA

- Discussion Timeline
- Flicker Analysis Methods
- Conclusions
- Sources

Flicker Discussions Timeline

Discussion Timeline

7.2017 — Start of Flicker Discussions

- Presentation by Industry
- Presentation by Eng. Consultant, Pterra
- Focus on limitations of IEEE 519-1992
- Intro to IEEE 1453-2015

9.2017 — Pterra Hosts Utility Training Session on IEEE 1453-2015

- Training Slides by Pterra on IEEE 1453-2015
- JU, DPS, and Industry agree to stop using the GE Flicker Curve to evaluate flicker

1.2018 — JU Officially Changing Screening & CESIR Flicker Criteria

- Pterra proposes simplified flicker screen and detailed flicker assessment option
- Industry expresses concerns over conservativeness of Pterra's screen.

5.2018 — JU Accepts Pterra's Screen H and Detailed Flicker Study Post CESIR

- JU does not agree with the Industry's concerns
- JU and Industry agree to 6-month trial period using conservative assumptions
- Will be re-assessed in Q1.2019

6.2018 — 6-Month Trial Starts

- JU will track number of projects that fail new Screen H compared to older GE Flicker Curve and report to ITWG.

Discussion Timeline Continued

10.2018

Industry Presentation Expresses Concerns Over Pterra Screen

- Industry requests to expedite review of Pterra Screen due to negative feedback from developers
- JU and DPS deny request and decide to finish 6-month trial

3.2019

JU and Industry Present on Collected Data during 6-Month Trial

- Both presentations show increased rejection rates due to new Screen H
- DPS requests that ITWG determine how to modify the screen to make it less conservative.
- Pterra and Industry proposed revised screen

4.2019

JU Decides to Revise Screen H with Pterra's Recommendation

- ITWG decides to document screen and time-series analysis changes
- Industry to create first draft for review at next meeting

5.2019

Industry Provides Flicker Analysis Guideline Draft

- JU disagrees with some aspects of the guideline and proposes their own
- Negotiations on what to be included in Guideline and SIR Filing continue

9.2019

SIR Filing Containing Screen H Changes Submitted to SIR-2019

- Final agreed-upon Screen H changes documented
- Continuing conversations required to discuss Time-Series Analysis portions of the flicker guideline

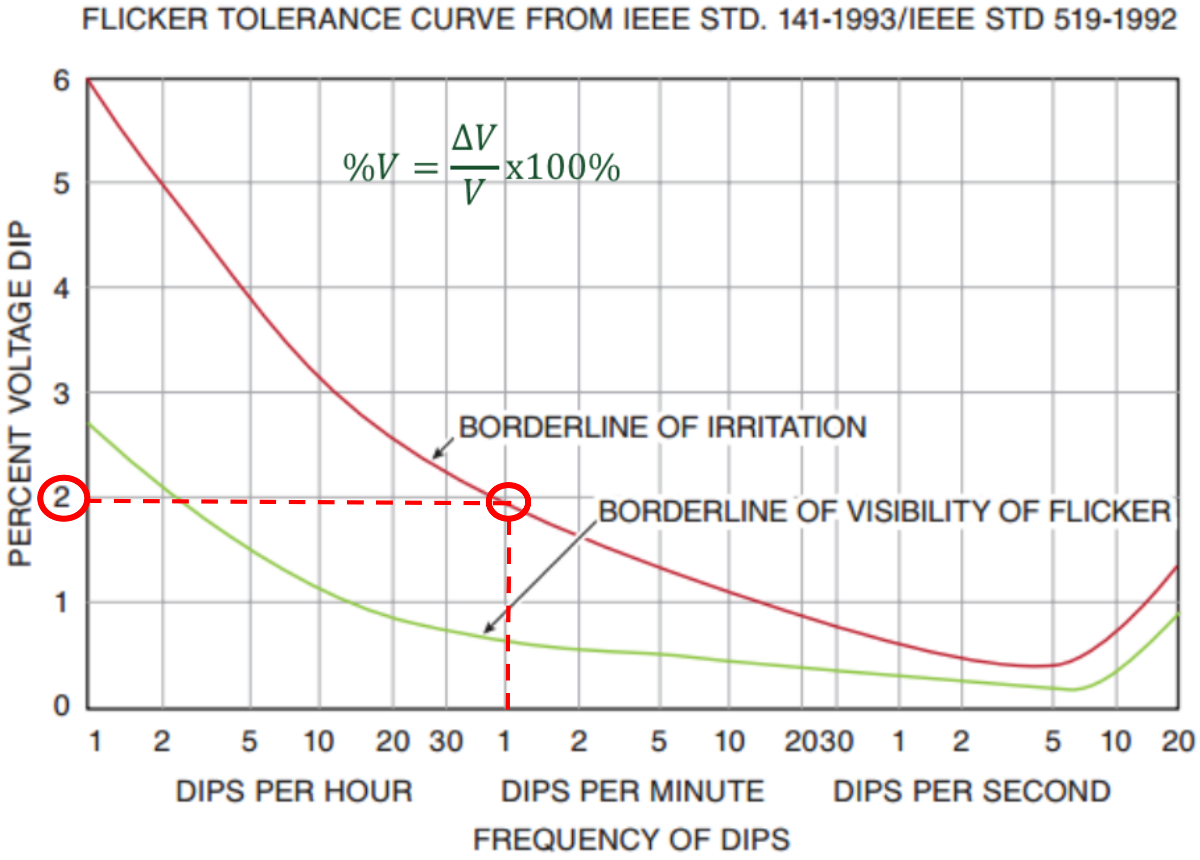
IEEE Standards Addressing Flicker

IEEE 519-1992

IEEE 519-1992: GE Flicker Curve

General Standard Information

- Introduces the GE Flicker Curve comprised of tolerance curves for visibility and irritation.
- Curve is based on square wave modulation and assumes constant frequency and magnitude of voltage fluctuation.
- Determining the flicker limit using GE Flicker Curve:
  - From a power flow model, calculate the maximum voltage change for the proposed Project at the PCC
  - Assume a frequency of fluctuations (in dips per minute or hour)
  - Look up the voltage drop from the corresponding region in the GE curve to determine if it is above either the borderline of visibility or borderline of irritation.
  - Example: National Grid NY previously used the Flicker Curve under the following assumptions: intersection of one dip/second and irritation curve seen on the graph to the right.



IEEE 519-1992: GE Flicker Curve

Concerns with Using the Flicker Curve

- PV voltage fluctuations are <u>not constant in either magnitude nor frequency</u>, and develop over a longer period as a function of changing cloud cover and insolation level
- Uses a static voltage change comparison (similar to Rapid Voltage Change analysis) as a proxy for determining Flicker impacts. Flicker severity is important, but so is frequency of occurrence which can be evaluated probabilistically utilizing the analysis methods in 1453-2015
- Different utilities use different assumptions when applying the GE Flicker Curve leading to major disparities in acceptable penetration levels between territories
- IEEE 519-1992 was superseded by IEEE 519-2014. This standard removed the GE Flicker Curve leaving 1453-2015 as the only living standard for evaluating flicker therefore the **GE Flicker Curve is no longer sanctioned or recommended by IEEE**.

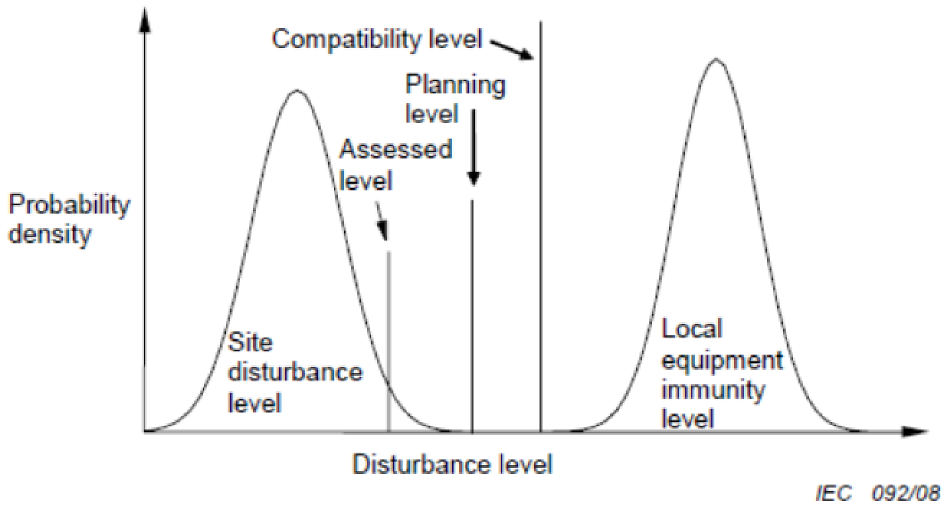
IEEE Standards Addressing Flicker

IEEE 1453-2015

IEEE 1453-2015:

General Standard Information

- New standard is a major improvement over the traditional flicker curve:
  - Can be used for voltage fluctuations with different shapes (square wave, gradual sine wave, or anything in between)
  - Can be used for completely random fluctuations and combinations of fluctuations
  - Can consider the impact of modulations caused by modern solid-state converters (including inverter-based PV)
- Flicker assessment methodology derived from the flickermeter standard IEC/TR 61000-3-7:2008
- Considers probability level for both short term and long term flicker impacts
- Once basic assumptions are agreed to, all Mass utilities would have much more consistent DG hosting capacity limits



IEEE 1453-2015:

Methods of Evaluating Projects Using 1453

- Simulation Method:
  - Using a time-series simulation tool would provide a more comprehensive analysis than using just a screening method
  - Time-series analysis with single-second resolution would be able to capture interactions between the daily changes in load, PV output, and distribution control systems
  - Output would reveal the magnitude of the impact as well as the duration and frequency of the impact directly correlating with the IEC flickermeter standard approach for determining acceptable flicker limits
- Screening Method:
  - Without performing detailed simulation - quantify the flicker effect by applying shape factors (discussed later)
  - Can use conservative assumptions to ensure system reliability is maintained without performing time-series analysis
  - Amount of data and calculations required to implement a screen takes much less time than aggregating and running a time-series simulation tool
- Hardware / Measurement Method:
  - Using flickermeter to measure, record, and analyze the voltage variation signal
  - Requires constant monitoring of the circuit and site in question
  - The most accurate way to determine flicker impacts but also the most costly

IEEE 1453-2015:

Flicker Calculation Methods Agreed to at the ITWG

- DPS supported the adoption of 1453-2015 and commissioned the engineering firm Pterra to facilitate the transition from the 519 to 1453.
- Pterra determined that Section 7 '<u>Estimating flicker levels at PCC of facilities serving fluctuating loads</u>' would be the basis of a new standard screen for estimating flicker impacts of a PV generator
- Below are the description of terms needed to implement said screen:
  - **<u>Flicker Severity:</u>** The intensity of flicker annoyance defined by the UIE IEC flicker measuring method and evaluated by the following quantities:
    - **Short-Term Flicker Severity [P_{st}]:** Flicker severity measured over a period of ten minutes
      - *E_{Pst} refers to individual project's short-term flicker severity while L_{Pst} refers to the grid's short-term flicker severity or planning level*
    - **Long-Term Flicker Severity [P_{lt}]:** Flicker severity calculated from a sequence of 12 consecutive P_{st} values (i.e. over a two hour interval)
      - *E_{Plt} refers to individual project's long-term flicker severity while L_{Plt} refers to the grid's long-term flicker severity or planning level*
  - **<u>Shape Factor</u> [F]:** Used to translate typical system modulation waveforms into equivalent sine or square wave modulation waveforms (i.e. an algebraic means of transforming typical system output fluctuation into a multiplier for determining flicker severity)
  - **<u>Relative Voltage Change</u> [d]:** Voltage change caused by the output fluctuations of a generator or load.
  - **<u>Relative Voltage Change at Max Planning Level</u> [$d_{Pst=1}$]:** Test point for rectangular voltage fluctuations used in the final Short-Term Flicker Severity calculation

IEEE 1453-2015:

Planning Limits

Flicker Emission Limits	Flicker Planning Levels		
	LV (X < 1 kV)	**MV** (1 kV < X < 34.5 kV)	**HV** (34.5 kV < X)
L_{Pst} (planning level)	1.0*	0.9*	0.8*
L_{Plt} (planning level)	0.8*	0.7*	0.6*
E_{Pst} (project contribution)	**X**	**0.35***	**X**
E_{Plt} (project contribution)	X	0.25*	X

* System planning levels discussed in IEEE 1453-2015

*Project contribution emission/flicker severity limit recommended in IEEE 1453.1 and IEC Std. 61000-7 and restated in IEEE 1547-2018

ITWG Flicker Screen (V1)

Calculation and Procedure Walkthrough

ITWG Flicker Screen (V1)

Flicker Calculation Method Overview

<u>Goal</u>: Calculate E_{Pst} and determine if it is less than the Flicker Severity Limit of 0.35 using Equation (14) below and the following procedures:

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

1. <u>Establish a Shape Factor using the graphs in Annex C of 1453-2015</u> to translate a typical PV system modulation waveform into equivalent sine or square modulation waveform
2. <u>Select appropriate relative voltage change in Table 4 of 1453-2015 (pg. 23)</u> for when flicker severity [P_{st}] is at its maximum value of one (1) which will provide our baseline relative voltage change [$d_{Pst=1}$]
3. <u>Calculate the relative voltage change of your generator</u> using Equation (15) from 1453-2015 by either performing a load flow analysis to determine the maximum voltage change at the PCC or by comparing the short circuit rating of the proposed generator to the available short circuit current at the PCC
4. <u>Calculate the proposed project's flicker severity</u> utilizing equation 14 of 1453-2015 (pg. 24)

ITWG Flicker Screen (V1)

Flicker Calculation Method - Step 1: Establish a Shape Factor

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

1. Establish a Shape Factor [F] using the graphs in Annex C of 1453-2015 to translate a typical PV system modulation waveform into equivalent sine or square modulation waveform
   a. Review graphs in Annex C and determine which best fits the conservative fluctuation case you are evaluating.

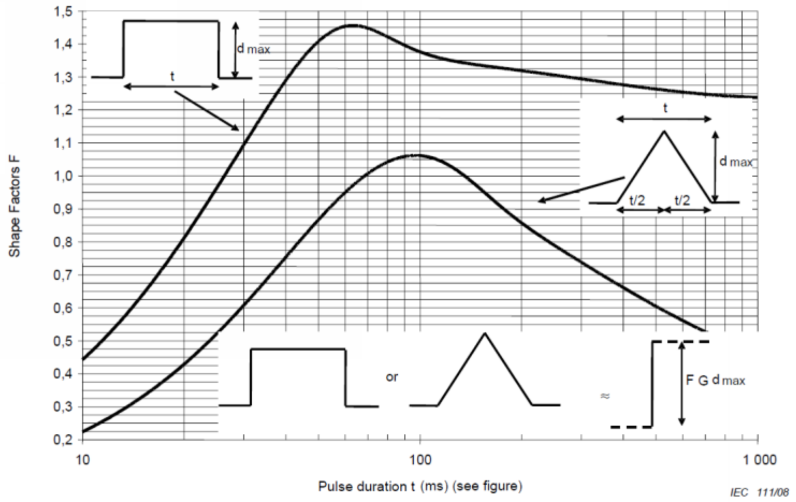


Figure C.1—Shape factor for pulse and ramp changes

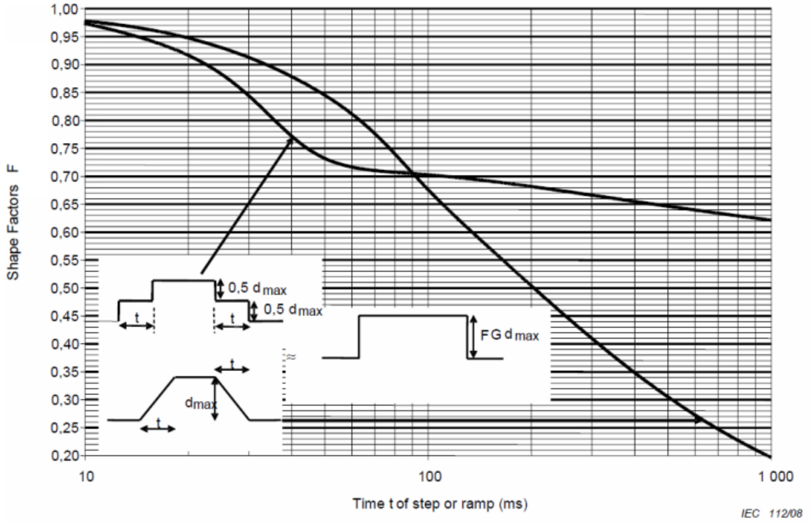


Figure C.2—Shape factor for double step and double ramp changes

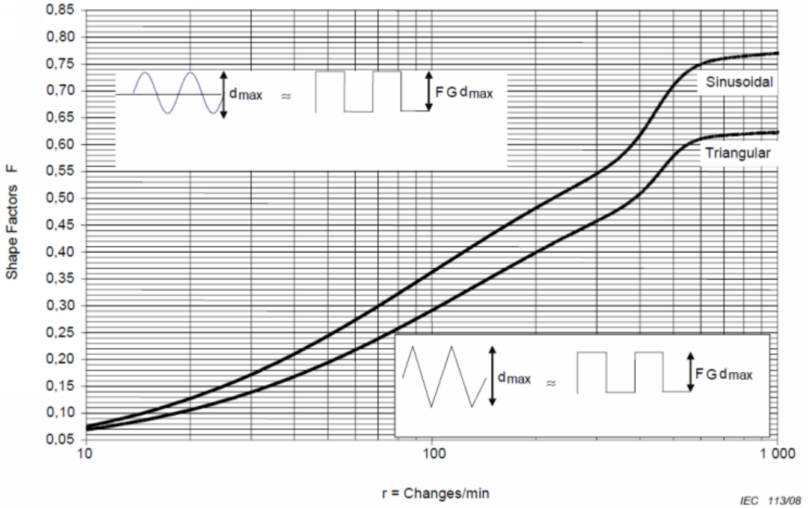


Figure C.3—Shape factor for sinusoidal and triangular changes

ITWG Flicker Screen (V1)

Flicker Calculation Method - Step 1: Establish a Shape Factor

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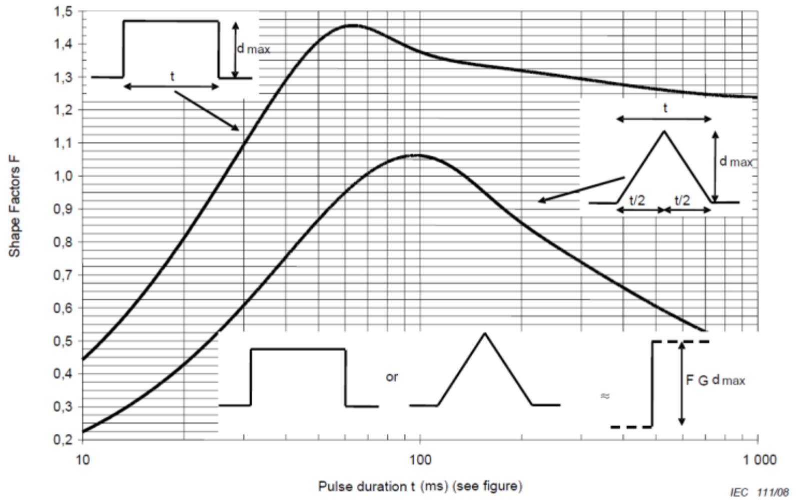

Figure C.1—Shape factor for pulse and ramp changes

Figure C.1 was evaluated by Pterra, however, this graph only increases the conservativeness of the already overly-conservative assumptions used by utilities when implementing the GE Flicker Curve.

As a refresher, utilities such as National Grid NY assumed a 0%-100%-0% dip in system output over a one (1) minute window. This means that a single ramp-up can be as long as 30-seconds with no limits on how fast the ramp can take. While discussing options for shape factor selection, the JU and Pterra agreed that a single-second full ramp-up or ramp-down was conservative enough for flicker calculations.

This graph assumes a full cycle ramp-up and ramp-down (i.e. 0%-100%-0%) over a maximum time window of one (1) second. Therefore, we are unable to use this graph to determine a shape factor for our conservative fluctuation case.

Figure C.2—Shape factor for double step and double ramp changes

Figure C.3—Shape factor for sinusoidal and triangular changes

ITWG Flicker Screen (V1)

Flicker Calculation Method - Step 1: Establish a Shape Factor

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

1. Establish a Shape Factor [F] using the graphs in Annex C of 1453-2015 to translate a typical PV system modulation waveform into equivalent sine or square modulation waveform
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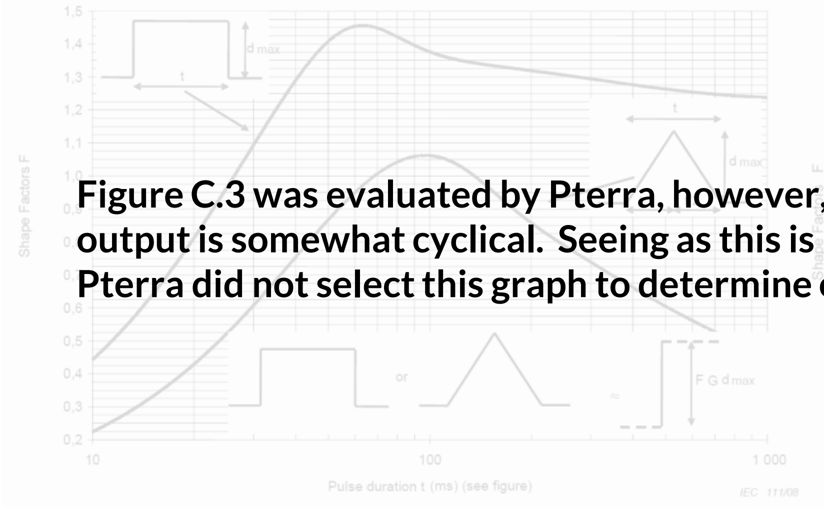

Figure C.1—Shape factor for pulse and ramp changes

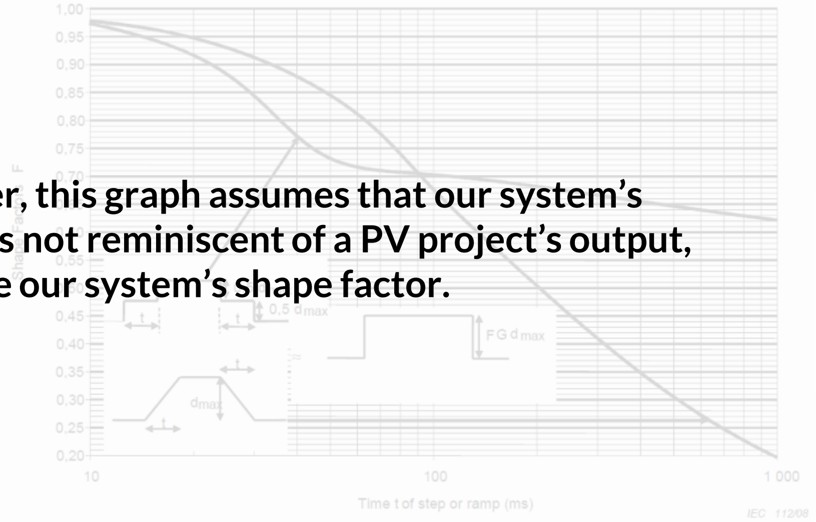

Figure C.2—Shape factor for double step and double ramp changes

Figure C.3 was evaluated by Pterra, however, this graph assumes that our system's output is somewhat cyclical. Seeing as this is not reminiscent of a PV project's output, Pterra did not select this graph to determine our system's shape factor.

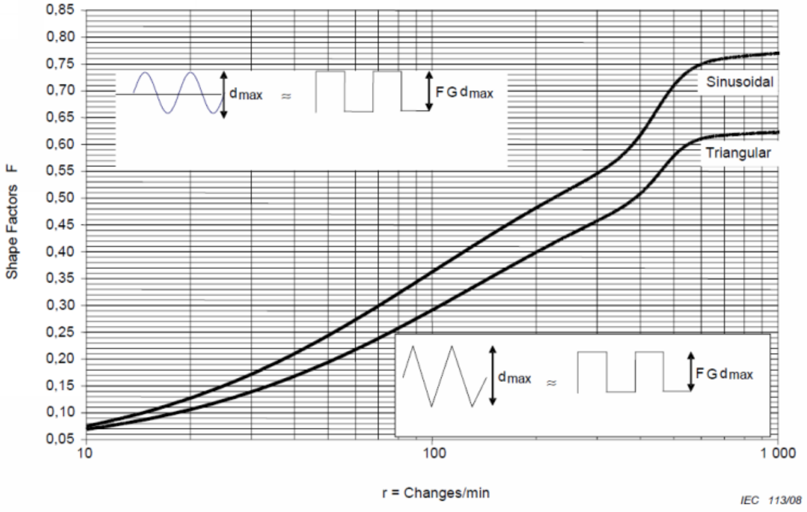

Figure C.3—Shape factor for sinusoidal and triangular changes

ITWG Flicker Screen (V1)

Flicker Calculation Method - Step 1: Establish a Shape Factor

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times \boxed{F} < 0.35$$

1. Establish a Shape Factor [F] using the graphs in Annex C of 1453-2015 to translate a typical PV system modulation waveform into equivalent sine or square modulation waveform
   a. Review graphs in Annex C and determine which best fits the conservative fluctuation case you are evaluating.

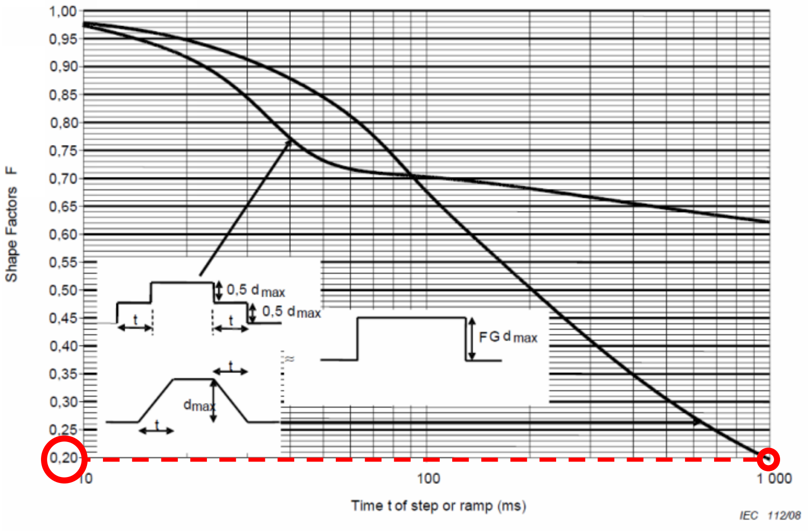

Figure C.2—Shape factor for double step and double ramp changes

Figure C.2 was evaluated by Pterra and chosen to determine our shape factor due to its similarity to the assumptions previously made when using the GE Flicker Curve. As mentioned earlier, the NY utilities assumed a complete ramp-up (0-100%) or complete ramp-down (100-0%) over the course of one (1) second.

Now that we have the time-window of the ramp, we then must select what curve to intersect with. To be as conservative as possible, the curve modeling the trapezoidal-like ramp up and down is closest to a full and nearly instantaneous step-change.

The intersection between these two is 0.2 which will be used as the shape factor for all PV evaluations in New York.

ITWG Flicker Screen (V1)

Flicker Calculation Method - Step 2: Determining Baseline Relative Voltage Change

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

1. Select appropriate relative voltage change in Table 4 of 1453-2015 (pg. 23) for when flicker severity [P_{st}] is at its maximum value of one (1) which will provide our baseline relative voltage change [d_{Pst}=1]
   a. Review Table 4 and determine the most conservative [$d_{Pst=1}$] value under the dips/minute assumptions you made previously

When determining [$d_{Pst=1}$], we need to look back at the assumptions we made for the dips/minute when using the GE Flicker Curve. The NY utilites were in agreement that one (1) dip/minute was sufficiently conservative enough for the previous selection of the shape factor, therefore, we will apply the same assumption here.

One (1) dip/minute is synonymous with two (2) ramps, one up and one down, per minute. Reviewing the graph, we see that Column 1 'Changes per Minute' has an option for two. We can select this row for our estimate:

The JU and Pterra decided to use the 120V [$d_{Pst=1}$] value for two changes/minute which is 2.568% but the reasoning behind why this was selected over 230V is unknown. We can assume that it was an attempt to address flicker for the most likely lamps currently used by customers

IEEE Std 1453-2015
IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems

Table 4—P_{st} = 1 test points for rectangular voltage fluctuations (Walker [B46])

Col.1 Changes per minute	Col.2 Fluctuation Frequency Hz	Col.3 Pst=1 Relative voltage changes for unit flicker severity for 230 V lamps ΔV/V (%)	Col.4 Pst=1 Relative voltage changes for unit flicker severity for 120 V lamps ΔV/V (%)
0.1	0.000833	7.400	8.202
0.2	0.001667	4.580	5.232
0.4	0.003333	3.540	4.062
0.6	0.00500	3.200	3.645
1	0.00833	**2.724**	**3.166**
2	0.01667	**2.211**	**2.568**
3	0.02500	1.95	2.250
5	0.04167	1.64	1.899
7	0.05833	1.459	1.695

ITWG Flicker Screen (V1)

Flicker Calculation Method - Step 3: Calculate Relative Voltage Change by Proposed Site

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

2. Calculate the relative voltage change [*d*] of your generator using Equation (15) from 1453-2015 by either performing a load flow analysis to determine the maximum voltage change at the PCC or by comparing the short circuit rating of the proposed generator to the available short circuit current at the PCC

   a. Equation (15) for relative voltage change [*d*] has two parts: a exact value and an approximation. New York Utilities chose to use the approximation due to its simplicity when evaluating a project during the preliminary screening stage

$$d = \frac{\Delta V}{V_r} \approx \frac{\Delta S}{S_{sc}} \text{, where}$$

$\frac{\Delta V}{V_r}$ *is the max p.u. change in grid voltage found during voltage fluctuation analysis*

ΔS *is the maximum change in generation during a normal fluctuation* $(0 - 100\%)$

S_{SC} *is the short – circuit power at the PCC*

ITWG Flicker Screen (V1)

Flicker Calculation Method - Step 4: Calculate Flicker Severity and Compare to Limit

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

2. Calculate the proposed project's flicker severity utilizing Equation (14) of 1453-2015 (pg. 24)

$$E_{P_{st}} = \left(\frac{d}{2.568\%}\right) \times 0.2 < 0.35 \quad \text{, where}$$

Relative Voltage Change [d] is calculated on a project by project basis

ITWG Flicker Screen (V1)

Flicker Calculation Method - Example

- Givens:
  1. Shape Factor [F] = 0.2
  2. Relative Voltage Change when P_{st}=1 [d_{Pst}] = 2.568%
  3. Relative Voltage Change [d] = [$\Delta S/S_{SC}$]
     - Generator Maximum Fluctuation in Power [ΔS] = 5,000 kVA
     - Circuit Short Circuit Power [S_{SC}] = 33,677 kVA

$$d \approx \frac{\Delta S}{S_{sc}} = \frac{5{,}000\ kVA}{33{,}677k\ kVA} = 0.148$$

$$P_{st} = \left(\frac{0.148}{0.02568}\right) \times 0.2 \approx 1.153$$

$$\Rightarrow 1.153 \gg 0.35$$

Project **Fails** Flicker Screening

Pterra Flicker Screen V1.0 Concerns

6-Month Trial and Results

- JU, DPS, and Industry agree to perform 6-month trial to see if the Industry's concerns regarding over-conservative assumptions leading to even more failed projects is valid.
- Group also decides to create an additional avenue for flicker review in the form of a time-series analysis performed by experienced engineering firms post-CESIR per recommendations in IEEE 1453-2015.
- After the 6 months are up, the collected data showed a significant increase in the number of failed projects due to flicker concerns. Of those projects that failed and went to a detailed time-series analysis, all had passed the detailed study which yielded final E_{Pst} values several orders of magnitude less than the screen.
    a. Example 1: A 5 MW project installed in New York failed the flicker screen with an E_{Pst} value of 0.39. Once analyzed during the flicker detailed study, the final E_{Pst} was 0.041, a decrease of approximately 90%.
    b. Example 2: A 2.5 MW project installed in New York failed the flicker screen with an E_{Pst} value of 0.52. Once analyzed during the flicker detailed study, the final E_{Pst} was 0.18, a decrease of approximately 65%.
- The JU and DPS agreed to reopen the screen for discussion.
- Both Pterra and the Industry propose modifications of which Pterra's method is selected as a replacement.

ITWG Flicker Screen (V2)

Flicker Calculation Method Overview

Goal: Calculate $E_{P_{st}}$ and determine if it is less than the Flicker Severity Limit of 0.35 using Equation (14) below and the following procedures:

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

1. Establish a Shape Factor using the graphs in Annex C of 1453-2015 to translate a typical PV system modulation waveform into equivalent sine or square modulation waveform **- Same**
2. Select appropriate relative voltage change in Table 4 of 1453-2015 (pg. 23) for when flicker severity [P_{st}] is at its maximum value of one (1) which will provide our baseline relative voltage change [$d_{P_{st}=1}$] **- Same**
3. **Calculate the relative voltage change of your generator using Equation (17) from 1453-2015 by performing a short circuit analysis to determine the positive sequence impedance components**
4. Calculate the proposed project's flicker severity utilizing equation 14 of 1453-2015 (pg. 24) **- Same**

ITWG Flicker Screen (V2)

Flicker Calculation Method - Step 3: Calculate Relative Voltage Change by Proposed Site

$$E_{P_{st}} = \left(\frac{d}{d_{P_{st}=1}}\right) \times F < 0.35$$

2. Calculate the relative voltage change [*d*] of your generator using Equation (17) from 1453-2015 by performing a short-circuit analysis to determine the positive sequence impedance components

$$d = \frac{R_L \times \Delta P + X_L \times \Delta Q}{(V_r)^2}, when \frac{X_L}{R_L} < 5$$

$$d = \frac{\Delta V}{V_r} \approx \frac{\Delta S}{S_{sc}}, when \frac{X_L}{R_L} > 5$$

X_L *is the positive sequence reactance of the circuit at the PCC*

R_L *is the positive sequence resistance of the circuit at the PCC*

ΔP *is the maximum change in real power of the generator (i.e. 100% of nameplate)*

ΔQ *is the maximum change in reactive power of the generator (zero if at unity p.f.)*

V_r *is the circuit voltage*

ITWG Flicker Screen (V1)

Flicker Calculation Method - Example

- Givens:
  1. Shape Factor [F] = 0.2
  2. Relative Voltage Change when P_{st}=1 [d_{Pst}] = 2.568%
  3. Relative Voltage Change [*d*] =
     - Generator Maximum Fluctuation in Real Power [ΔP] = 5,000 kVA
     - Generator Maximum Fluctuation in Reactive Power [ΔQ] = 0 kVA
     - Positive Sequence Reactance [X_L] = 2.9784
     - Positive Sequence Reactance [R_L] = 1.0042

$$\frac{X_L}{R_L} = \frac{2.9784}{1.0042} = 2.966 < 5$$

$$d = \frac{R_L \times \Delta P + X_L \times \Delta Q}{(V_r)^2}$$

$$d = \frac{(1.0042 \times 5000\ kVA) + (2.9784 \times 0)}{13.2^2}$$

$$d = 2.16\%$$

$$P_{st} = \left(\frac{2.16\%}{2.568\%}\right) \times 0.2$$

$$P_{st} = 0.168 < 0.35$$

Project Passes Flicker Screening

Flicker Evaluation Methods Compared

GE Flicker Curve vs. Pterra V1.0 vs. Pterra V2.0 vs. Time-Series Analysis

- Project Assumptions:
  - 5,000 kW PV System
  - 2-Miles from Substation
  - Set to Operate at Unity Power Factor
- Grid Characteristics:
  - 3P Short Circuit Current at POI: SSC = 3,240A
  - Positive Sequence Impedance: Z(+) = 0.3455 + j1.2986
  - Largest Voltage Fluctuation: VRVC = 1.59%
- Utility-Specific Parameters:
  - GE Flicker Curve - Assume 1 dips/min and follow Irritation Curve which is approximately 2%

	GE Flicker Curve	Pterra Screen V1.0	Pterra Screen V2.0	Time-Series Analysis
PASS / FAIL				

Flicker Evaluation Methods Compared

GE Flicker Curve vs. Pterra V1.0 vs. Pterra V2.0 vs. Time-Series Analysis

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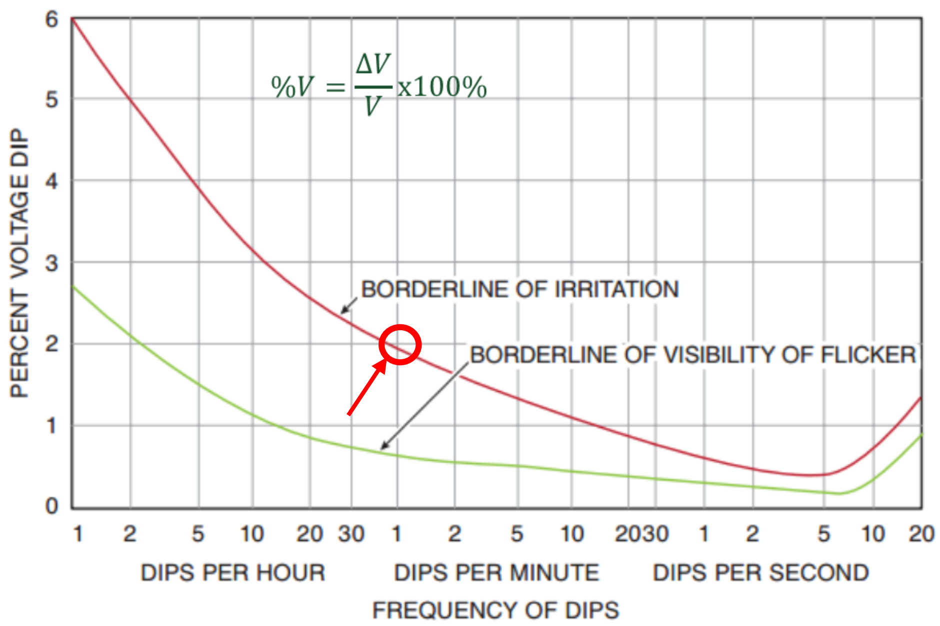
FLICKER TOLERANCE CURVE FROM IEEE STD. 141-1993/IEEE STD 519-1992



	GE Flicker Curve	Pterra Screen V1.0	Pterra Screen V2.0	Time-Series Analysis
PASS / FAIL	1.59% < 2% ⇒ **PASS**			

Flicker Evaluation Methods Compared

*GE Flicker Curve vs. **Pterra V1.0** vs. Pterra V2.0 vs. Time-Series Analysis*

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  - Largest Voltage Fluctuation: VRVC = 1.59%
- Utility-Specific Parameters:
  - GE Flicker Curve - Assume 1 dips/min and follow Irritation Curve which is approximately 2%

$$d \approx \frac{\Delta S}{S_{sc}} = \frac{378\ A}{3{,}240\ A} = 0.117$$

$$P_{st} = \left(\frac{0.117}{0.02568}\right) \times 0.2 \approx 0.9105$$

$$P_{st} \approx 0.9105 \gg 0.35$$

	GE Flicker Curve	Pterra Screen V1.0	Pterra Screen V2.0	Time-Series Analysis
PASS / FAIL	1.59% < 2% ⇒ **PASS**	0.9105 > 0.35 ⇒ **FAIL**		

Flicker Evaluation Methods Compared

*GE Flicker Curve vs. Pterra V1.0 vs. **Pterra V2.0** vs. Time-Series Analysis*

- Project Assumptions:
  - 5,000 kW PV System
  - 2-Miles from Substation
  - Set to Operate at Unity Power Factor
- Grid Characteristics:
  - 3P Short Circuit Current at POI: SSC = 3,240A
  - Positive Sequence Impedance: Z(+) = 0.3455 + j1.2986
  - Largest Voltage Fluctuation: VRVC = 1.59%
- Utility-Specific Parameters:
  - GE Flicker Curve - Assume 1 dips/min and follow Irritation Curve which is approximately 2%

$$\frac{X_L}{R_L} = \frac{1.2986}{0.3455} = 3.76 < 5$$

$$d = \frac{R_L \times \Delta P + X_L \times \Delta Q}{(V_r)^2}$$

$$d = \frac{(0.3455 \times 5000\, kVA) + (1.2986 \times 0)}{13.2^2}$$

$$d = 0.99\%$$

$$P_{st} = \left(\frac{0.99\%}{2.568\%}\right) \times 0.2$$

$$P_{st} = 0.078 \ll 0.35$$

	GE Flicker Curve	Pterra Screen V1.0	Pterra Screen V2.0	Time-Series Analysis
PASS / FAIL	1.59% < 2% ⇒ **PASS**	0.9105 > 0.35 ⇒ **FAIL**	0.078 < 0.35 ⇒ **PASS**	

Flicker Evaluation Methods Compared

GE Flicker Curve vs. Pterra V1.0 vs. Pterra V2.0 vs. Time-Series Analysis

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- Time-Series Analysis performed by Northern Plains Power
- Took geographic smoothing into account
- Only considers the individual project and not other DG located on the same feeder
- Redacted Report Link

	GE Flicker Curve	Pterra Screen V1.0	Pterra Screen V2.0	Time-Series Analysis
PASS / FAIL	1.59% < 2% ⇒ **PASS**	0.9105 > 0.35 ⇒ **FAIL**	0.078 < 0.35 ⇒ **PASS**	0.041 < 0.35 ⇒ **PASS**

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Conclusions

Lessons Learned and Recommendation

Conclusions

- IEEE 519-1992 was superseded by IEEE 519-2014 which removed all notes about the GE Flicker Curve
- The only living standard that addresses flicker is IEEE 1453-2015
- There are several screens that can be derived from IEEE 1453-2015 and IEEE 1547-2018, however, a time-series analysis is the only true means of determining flicker on a circuit
- Of the screens that were developed at the ITWG, the Pterra Screen V1.0 used an approximation for relative voltage change (*d*) which lead to an increased failure rate of projects
- Pterra Screen V2.0 better approximates relative voltage change and the resulting flicker severity calculation yields an approximation that is several magnitudes closer to the result found in the time-series analysis

Borrego believes that the Mass Utilities replace their existing flicker analysis with Pterra V2.0 and, if failed, provide an option to developers to pursue a time-series analysis.

Sources

- IEEE 519-1992 - Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- IEEE 1453-2015 - Recommended Practice for the Analysis of Fluctuating Installations on Power Systems
- IEEE 1547-2018 - Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- IEC 61000-3-7, Electromagnetic compatibility (EMC) - Limits - Assessment of emission limits for the connection of fluctuating installations to MV, HV, and EHV power systems.
- “Voltage Flicker for SIR Screen H Workshop” by Ric Austria, Ketut Dartawan, and Amin Najafabadi (Pterra)