# Voltage Flicker Analysis for SIR Screen H and CESIR

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# References

- New York State Standardized Interconnection Requirements (SIR) and Application Process (February 2017), Screen H:
  - "b. Can it be determined within the Supplemental Review that the voltage fluctuation is within acceptable limits as defined by IEEE 1453 or utility practice similar to IEEE 1453?"
- IEEE-1453-2015 defines the term "flicker" as a
  - "subjective impression of fluctuating luminance caused by voltage fluctuations."
    - In our opinion Screen F is not about flicker, per this definition
    - Neither are: (1) *equipment impact of voltage fluctuations such as tap-cycling*, nor (2) *step changes in voltage.* Both are significant for interconnections, but are not about flicker per the 1453 definition.
- CESIR requirement, SIR at p. 13:
  - "Electrical studies as requested by the utility to demonstrate that the design is within acceptable limits, inclusive and not limited to the following: … flicker … ."

# Objectives

- Provide technical information regarding flicker with respect to PV interconnections in distribution systems
- Discuss IEEE 519-1992 (use of GE Flicker Curve for screen H)
- Discuss IEEE-1453-2015 (use of flickermeter for screen H and CESIR)
- Provide sample screening and detailed studies using IEEE-1453-2015
  - Note: DPS has engaged Pterra to develop training and reference material on the application of IEEE 1453 for screening and potential detailed studies

# Voltage Flicker

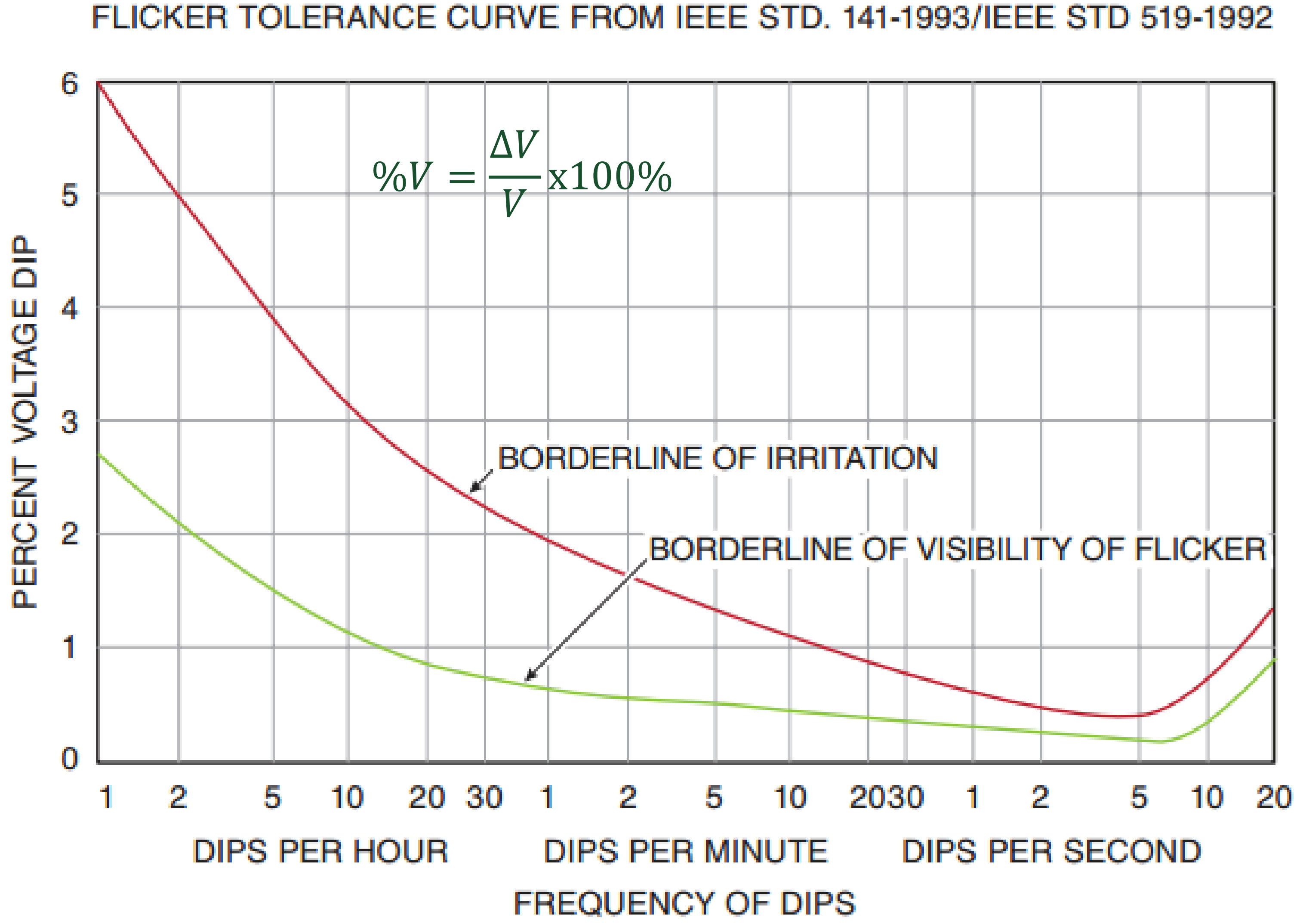
- IEEE-100 Standard Dictionary definition: Flicker is the perceptible change in electric light source intensity due to voltage fluctuation of input voltage.
- Voltage fluctuations are responsible for noticeable flicker:
  - Could be caused by **rapidly** changing loads / PV generation due to changing cloud cover
  - **Magnitude** and **frequency** of voltage fluctuations
- 3 major components:

Rapidly Changing Loads/Generation → Voltage Fluctuation (mag. & freq.) → Human response to change in light intensity

# IEEE 519-1992

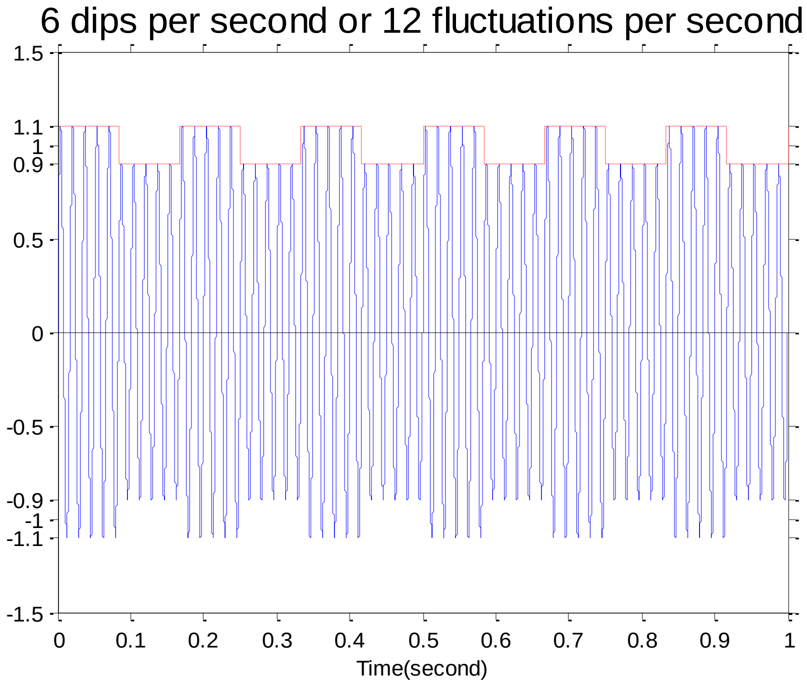
- Introduces the GE Flicker Curve comprised of tolerance curves for Visibility & Irritation

- Noticeable flicker and frequency of voltage fluctuations:
  - 8.8 Hz is most sensitive frequency for human (voltage change as low as 0.5% could cause irritation)
  - People most sensitive around 5 – 10 dips/seconds
  - much less than the 50 Hz or 60 Hz supply frequency



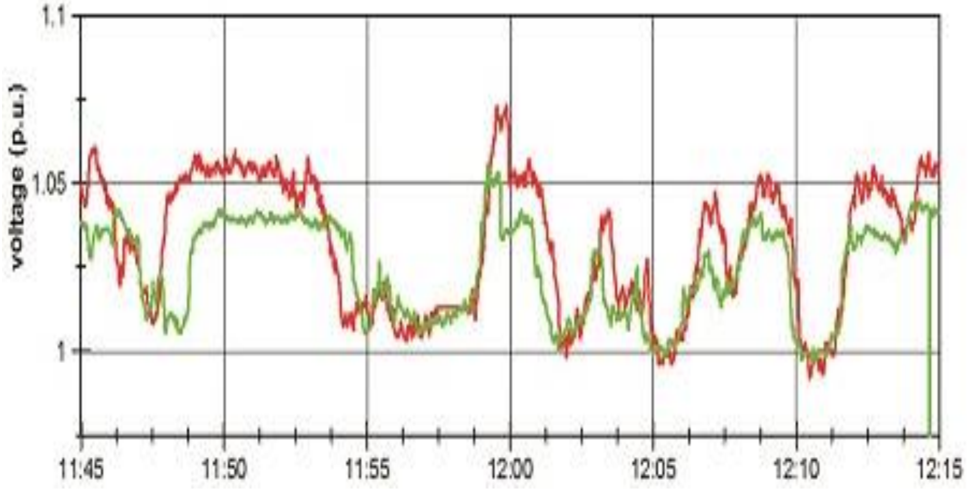
# IEEE 519-1992

- GE Flicker Curve is based on:
  - Square wave modulation
  - Constant voltage fluctuation magnitude and frequency such that it can be represented as a single point on the curve




- PV voltage fluctuations are not constant in either magnitude nor frequency, and develop over a longer period as a function of changing cloud cover and insolation level

**Voltage fluctuation on high penetration feeder**




30 minute plot of RMS voltage at two different locations on a feeder with high PV penetration

# IEEE 519-1992

- IEEE-519-2014 supersedes the 1992 version and this version has removed the GE Flicker Curve
- For screening under SIR using the GE flicker curve, one generally performs the following steps:
  - From a power flow model, calculate the maximum voltage drop for the proposed Project at the PCC (Point of Common Coupling).
  - Assume a frequency of fluctuation (in dips per minute/hour)
  - Look up the voltage drop for the corresponding region in the GE curve to determine if it is above the either the borderline of visibility or borderline of irritation.
- Different utilities use the flicker curve differently

**Table 1: Application of the GE Flicker Curve by Utility**

| | Con Edison[8] | Central Hudson | National Grid | NYSEG / RG&E | Orange and Rockland |
|---|---|---|---|---|---|
| Percent Voltage Dip | N/A | 2% | 2% | 1.2% | 0.7% |
| Dips Per Minute | N/A | 1 | 1 | 10[9] | 1 |
| Borderline Curve | N/A | Irritation | Irritation | Visibility | Visibility |

9 Per hour

# Transitioning from IEEE 519-1992

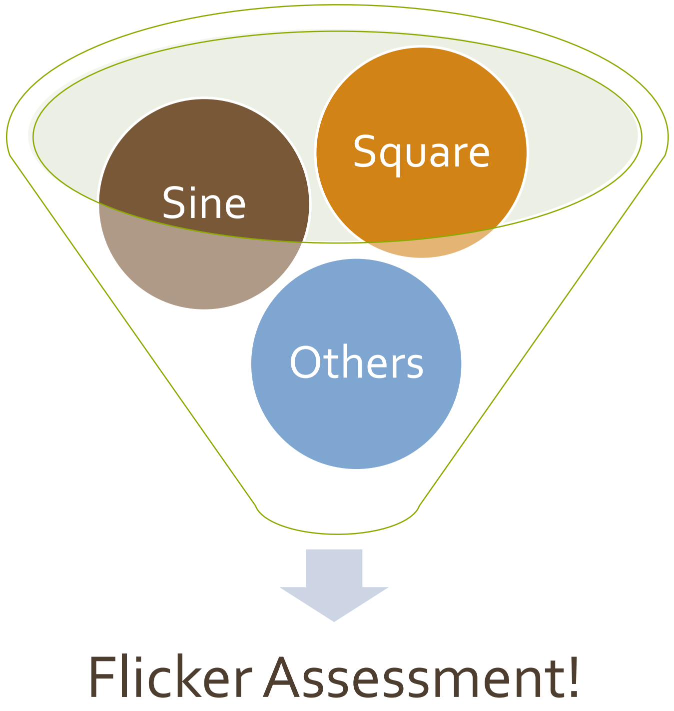
GE Flicker Curve is based on square wave modulation / Step changes

Variety of modern power electronic equipment on the system nowadays could cause voltage fluctuation with different shapes:

- Smooth / gradual Changes (sine wave modulation)
- Square wave modulation (sudden/step changes)
- Anything in between

There are significant differences in perception for step changes as opposed to gradual changes

- The slope of transition should also be taken into consideration



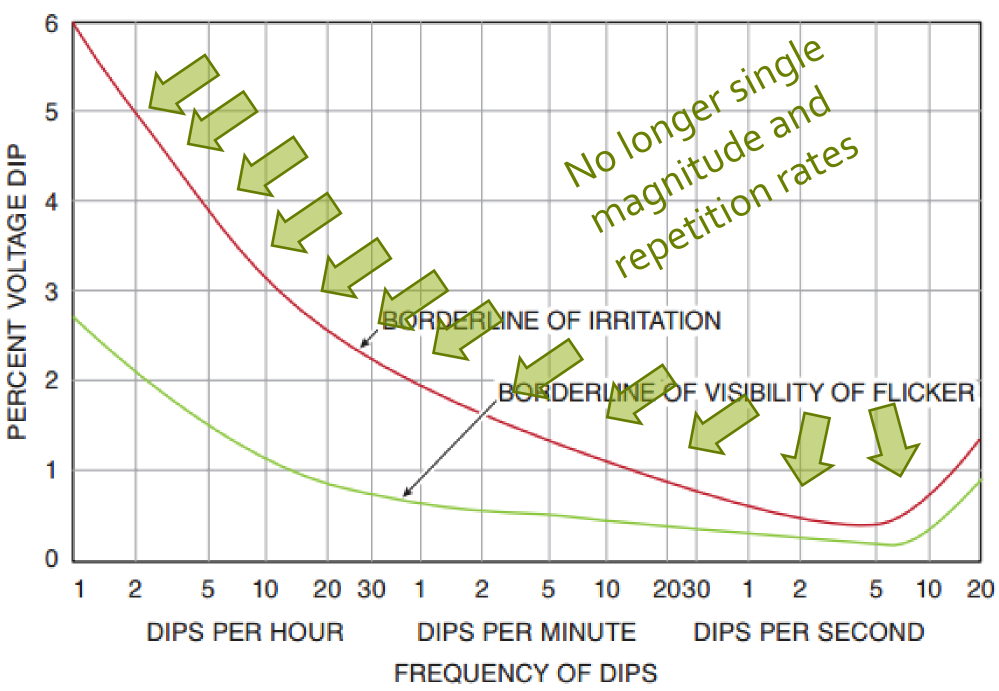
# Transitioning from IEEE 519-1992

- Modern power electronic equipment produce random fluctuations

- Random & combination fluctuations cannot be defined by the flicker curve – both amplitude and freq. of the fluctuations change continuously.
  - The point that defines such fluctuations moves continuously
  - Large change every 10 seconds and smaller change every second, etc.
  - No longer single magnitude and single repetition rates

GE Flicker Curve – designed for constant amplitude and constant frequency – single point that can be located in the curve

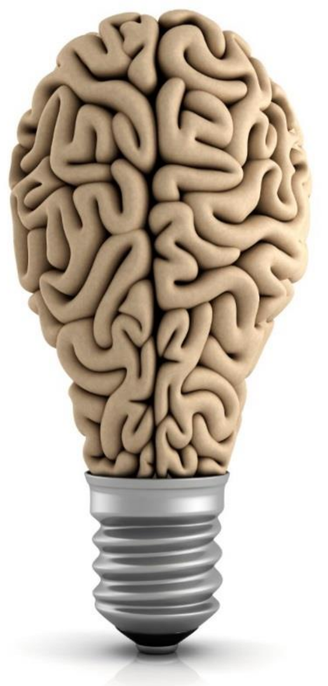
FLICKER TOLERANCE CURVE FROM IEEE STD. 141-1993/IEEE STD 519-1992



# IEEE-1453-2015

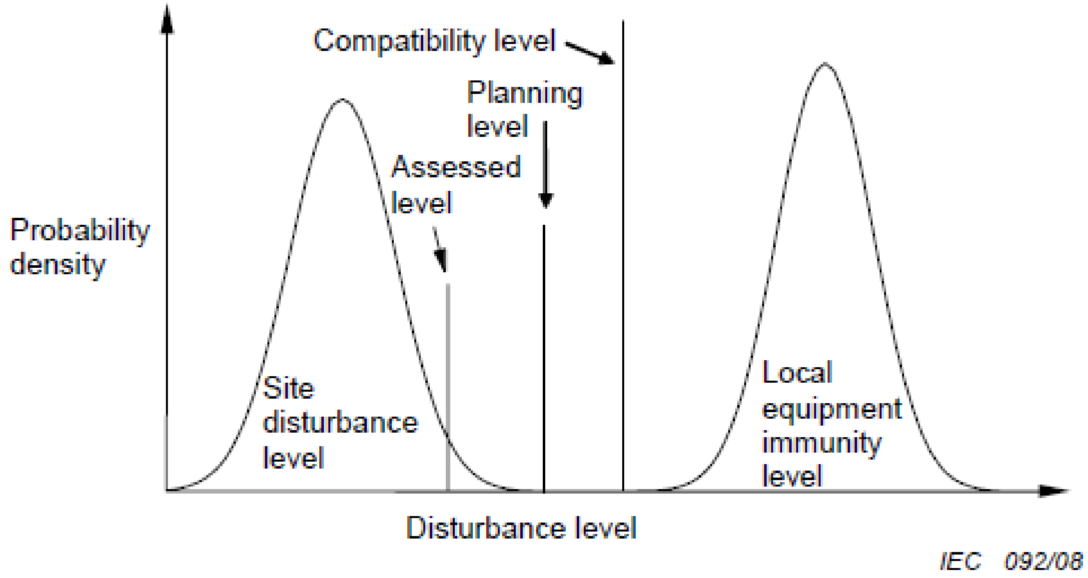
- Adopts the IEC Std. 6100-4-15 **flickermeter**
- A major improvement over the traditional flicker curve:
  - Can be used for voltage fluctuations with different shapes (square wave, gradual sine wave or anything in between)
  - Can be used for completely random fluctuations and combinations of fluctuations
  - Can consider the impact of modulations caused by modern solid-state converters (including inverter-based PV)
  - Will account for dosing that may come from intermittent changes in cloud cover
- IEEE 519-1992 is similar to IEEE 1453 in the sense that it was the recommended practice for evaluating voltage flicker, but is clearly outdated in terms of being able to capture impacts of modern devices such as inverter-based PV

Flickermeter models the complex "LAMP-EYE-BRAIN" Interaction to uniformly quantify flicker from a variety of fluctuations



# IEEE-1453-2015

- Flicker assessment methodology accounting for probability of emission levels from Project versus tolerance (immunity) levels for local customers.
  - (Source: IEC/TR 61000-3-7:2008, Fig. 2)
- Pst : short term flicker is based on a 10-minute interval
- Plt : long-term flicker – used for devices with duty cycles longer than 10 minutes (two hours are used in practice)



# IEEE-1453-2015

**IEEE 1453-2015 Recommended Flicker Limit (Statistical Compliance)**

| Planning Level<br>For Proposed Installation / Projects<br>95% / 99% Probability Level(*)<br>Minimum assessment level of one week | | | Compatibility Level<br>Existing Installation<br>95% Probability Level<br>Minimum 1 week assessment |
|---|---|---|---|
| | MV | HV-EHV | LV |
| Pst | 0.9 | 0.8 | 1.0 |
| Plt | 0.7 | 0.6 | 0.8 |

* Depending on system conditions to be determined by the system operator

## Statistical Compliance Sample:

95% mean that Pst level would not exceed the level more than 5% of the time

- It can exceed the level less than 5% of the time
- 1 week will have 1008 ten-minute Pst measurements
  out of the 1008, Pst can only be exceed in about 50 or less

# IEEE-1453-2015

- Considers probability level for both short term and long term flicker impact
  - Not only flicker severity is important, but also the frequency of occurrence
  - Attempt to measure the build up of customer annoyance
- Ensure consistent and fair application to all customers
  - by utilizing a numerical measure of flicker severity that is appropriate for periodic sudden fluctuations, gradual changes, and completely random fluctuations.
- Can be incorporated into simulation models to estimate future flicker and validate different flicker mitigation methods
- Recommended standard in the industry, internationally accepted, and more technically correct method of accessing voltage flicker from different sources, including PV generation

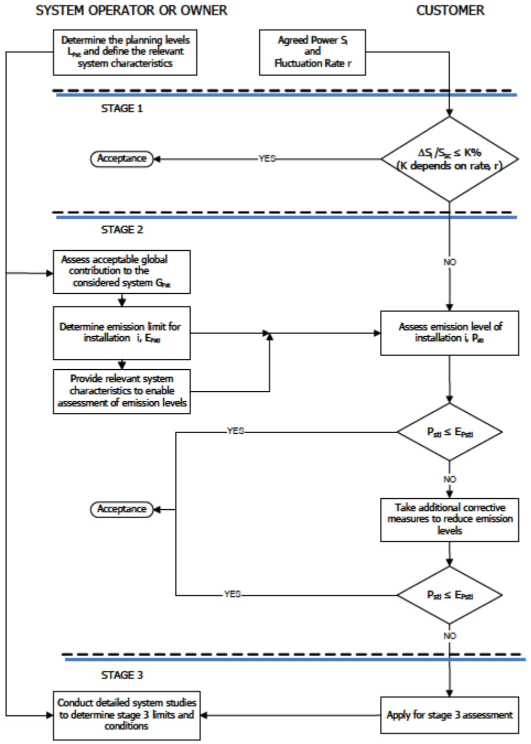
# IEEE 1453 Flickermeter – Assessment

- Screening Method – without performing detailed simulation - quantify the flicker effect by applying shape factors
- Simulation Method – using time series simulation tool (more comprehensive analysis than the screening method)
- Hardware / measurement Method – using flickermeter to measure, record, and analyze the voltage variation signal.

Proposed Projects

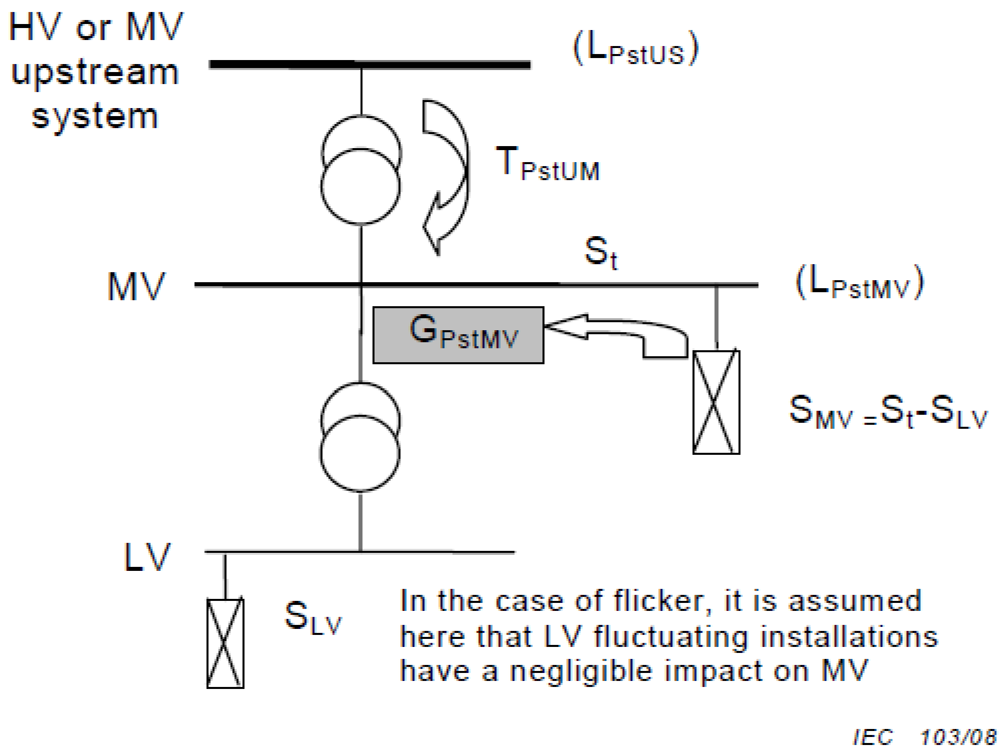
# IEEE-1453-2015 – A Screening Method

- Does not require detailed simulation and can be used for complying with Screen H.b
- Inputs:
  - Rated power & short circuit level (can be obtained from power flow model used in GE flicker method)

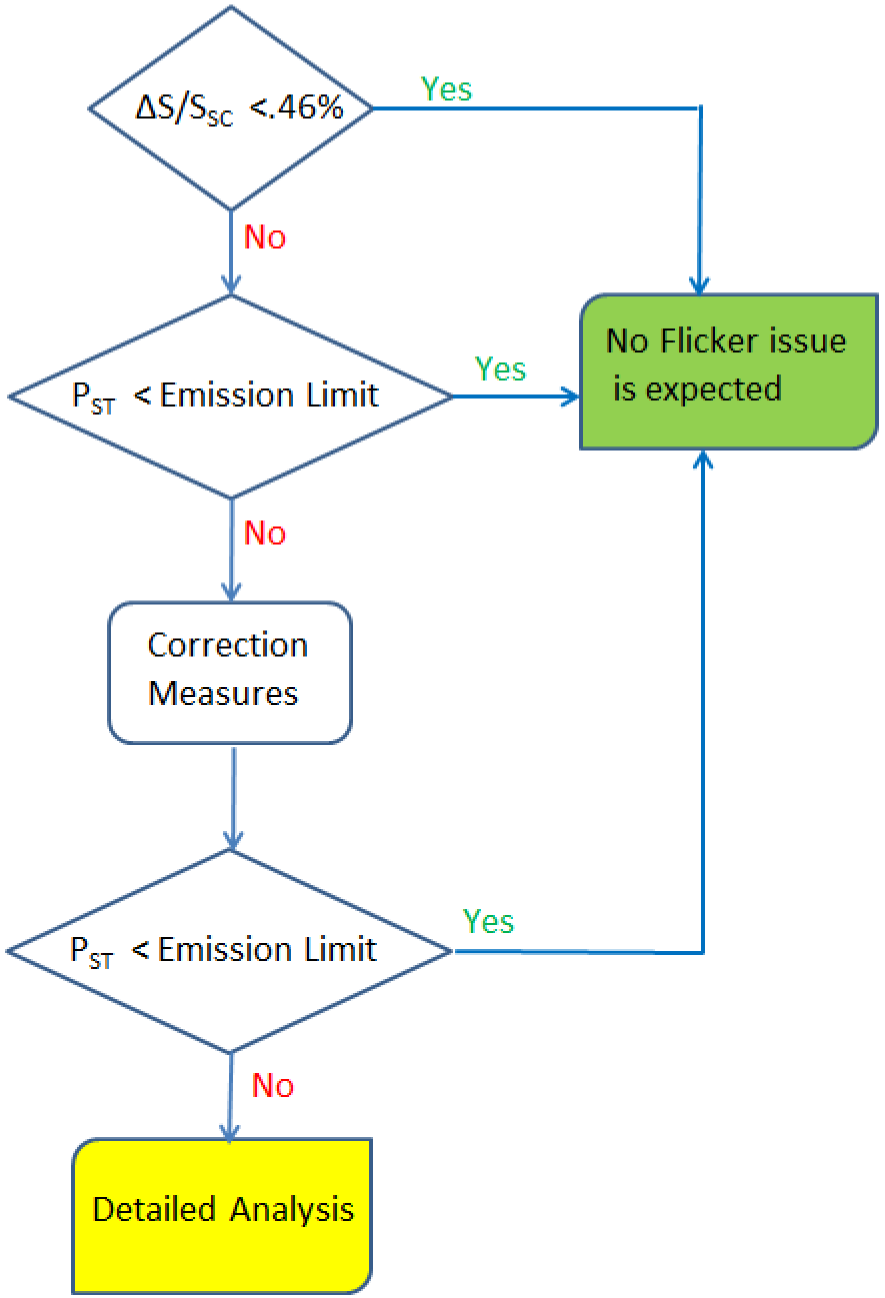


# Simplified Flowchart

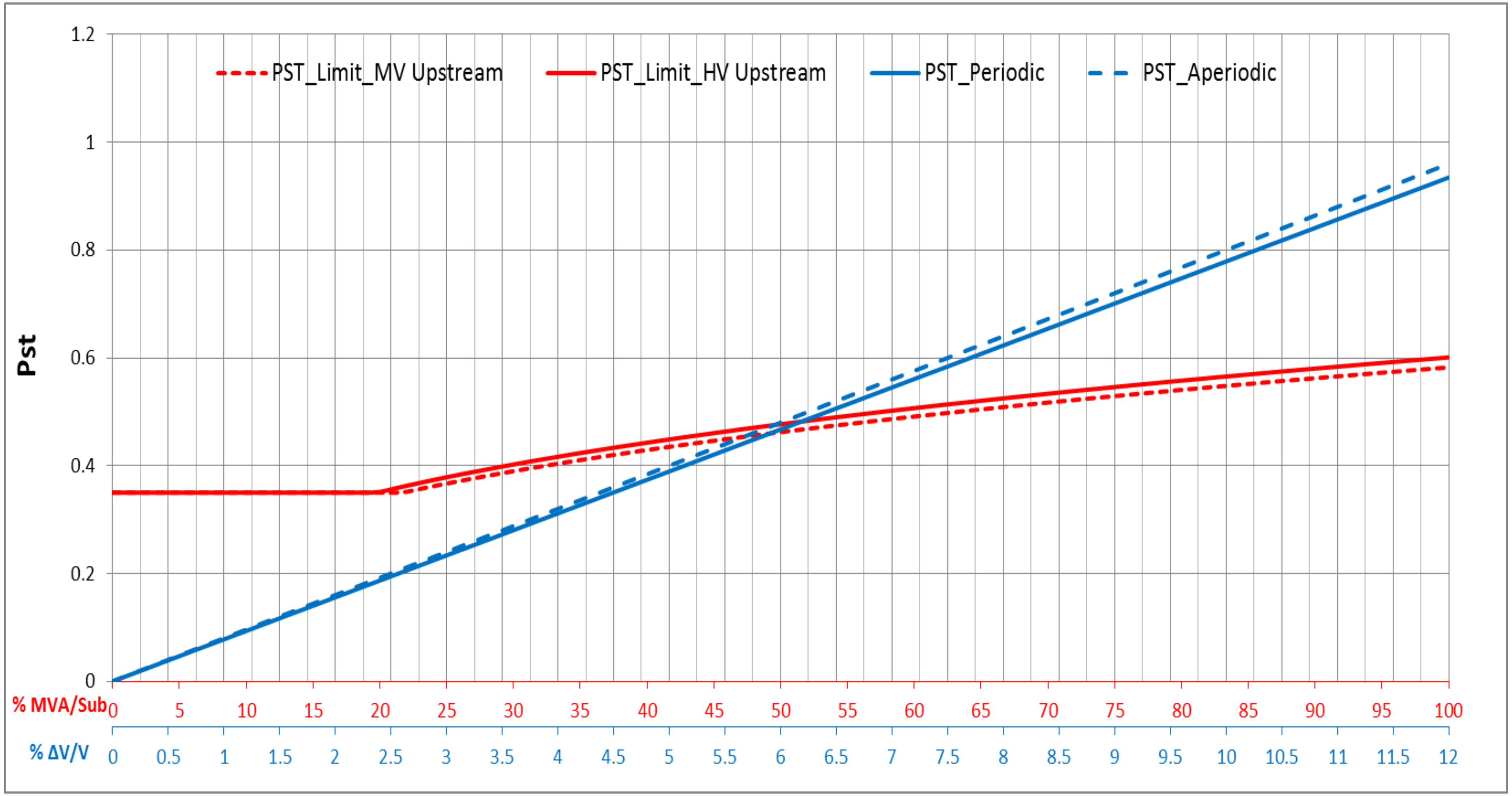
- What is emission limit?




(Adopted from IEEE 1453.1-2012)



# Simple Flicker Screen for PV Projects Connected to MV Radial Feeders



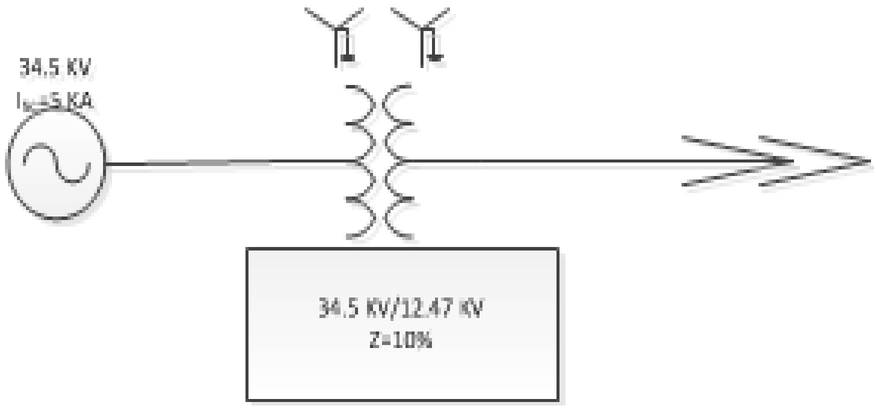
# A Simple Screening Example:

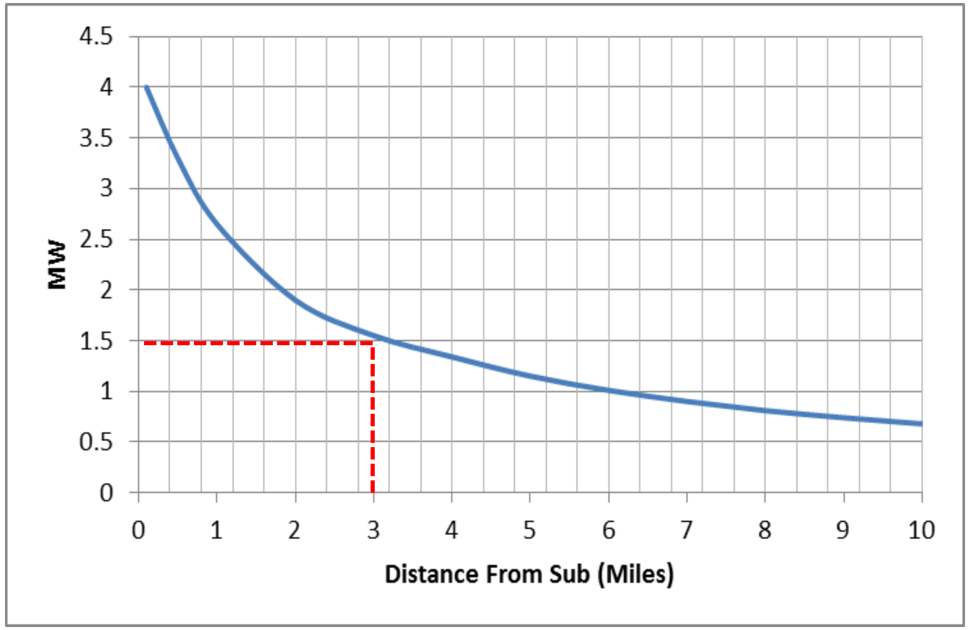
- 10 MVA sub transformer with Z=10%
- Short circuit Capability of

the system at 34.5 KV is equal to 5 KA

- Feeder is composed of OH lines with

4/0 phase and 1 neutral conductor




Details of Screening Method based on IEEE-1453 will be presented in a training session being prepared for August or September

# IEEE-1453-2015 – Detailed Analysis for CESIR

- Conventional power flow tool is not sufficient:
  - Generally use for snapshots of critical time period (e.g. peak and minimum load points) – This only give the magnitude of an impact at one instant in time.
  - PV output is highly variable and its impact may not be properly analyzed with traditional snapshot power flow approach
- Need power flow with "Time Series" simulation feature:
  - Able to capture time-dependent aspects of power flow: e.g. interaction between the daily changes in load and PV output and distribution control systems
  - Produce sequential steady state power flow solutions where the converged state of an iteration is used as the beginning state of the next ( 1-second resolution is typically used)
  - Able to capture magnitude of the impact as well as the duration and frequency of the impact, and dosing effects as well

# IEEE-1453-2015 – Detailed Analysis for CESIR

## Challenges

- Familiarity with the methodology and necessary tools to perform the analysis for detailed analysis (CESIR)
- May need to convert circuit model data

- Require more data than the traditional flicker curve method
  - Irradiance data ( 1 – 2 seconds resolution)
  - Feeder load data
    - might not be available or typically available in lower resolution (15 min – 1 hour resolution)

## Potential Solutions

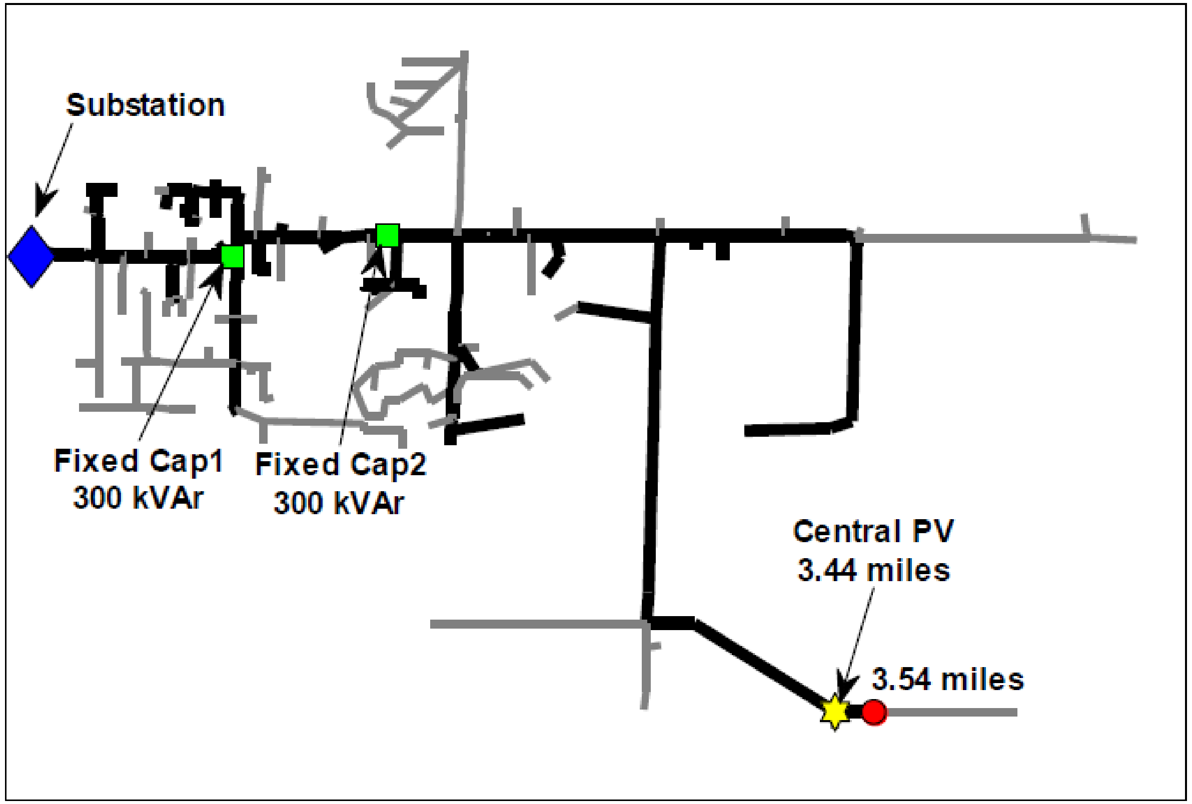
- Training & Learn from Others
- Improve Future Data Collection
  Use typical data

# Detailed Study Examples

**SANDIA REPORT**
SAND2013-0537
Unlimited Release
January 2013

**Time Series Power Flow Analysis for Distribution Connected PV Generation**

**Demonstrates a method for flicker assessment using IEEE 1453 standard**




| | |
|---|---|
| Load[1] | Peak: 1.7 MVA<br>Min: 0.7 MVA |
| Length (mi)[2] | 3.54 |
| Main Conductor Rating | 274 Amps |
| Substation Transformer | 46-12.47 kV<br>9.4 MVA FA |
| Substation Transformer Load[1] | Peak: 4.1 MVA<br>Min: 3.9 MVA |
| LTC Voltage Settings | 123V, 2V Bandwidth, 60 sec delay, 4+j3 V LDC |
| Load Class[3] | 56% Residential, 44% Commercial |
| Capacitor Banks | 300 kVAr Fixed |

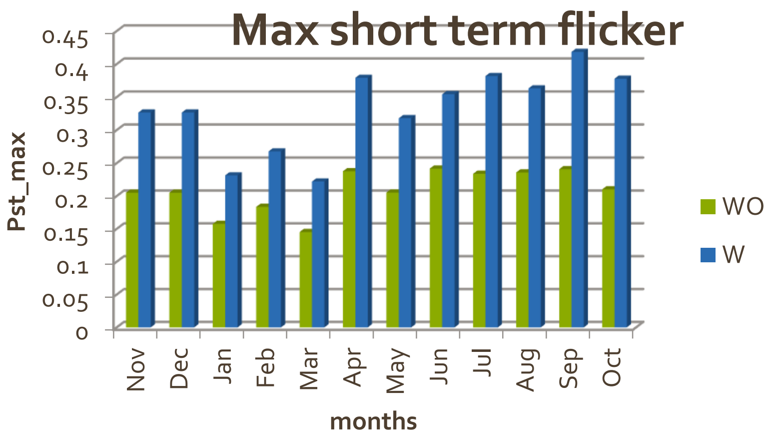
- 1.75 MW PV Plant on the edge of the feeder (3.44 miles from sub).
- Near end of the feeder – conservative for flicker assessment
- PV is 250% of feeder minimum load
- PV is 100% of feeder peak load

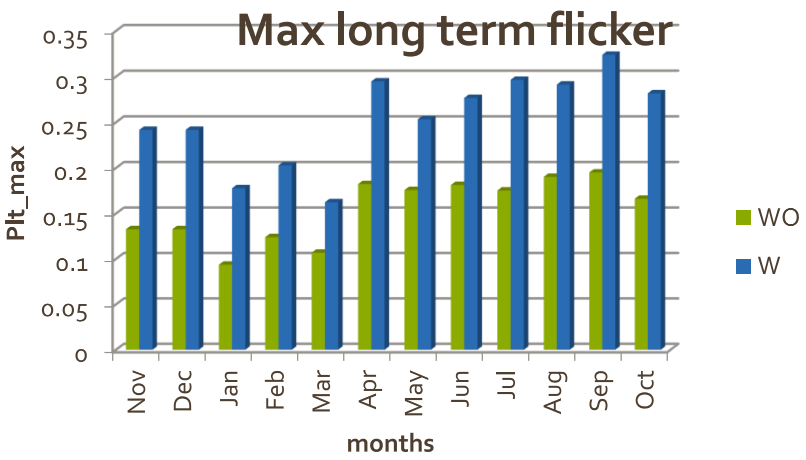
# Detailed Study Examples

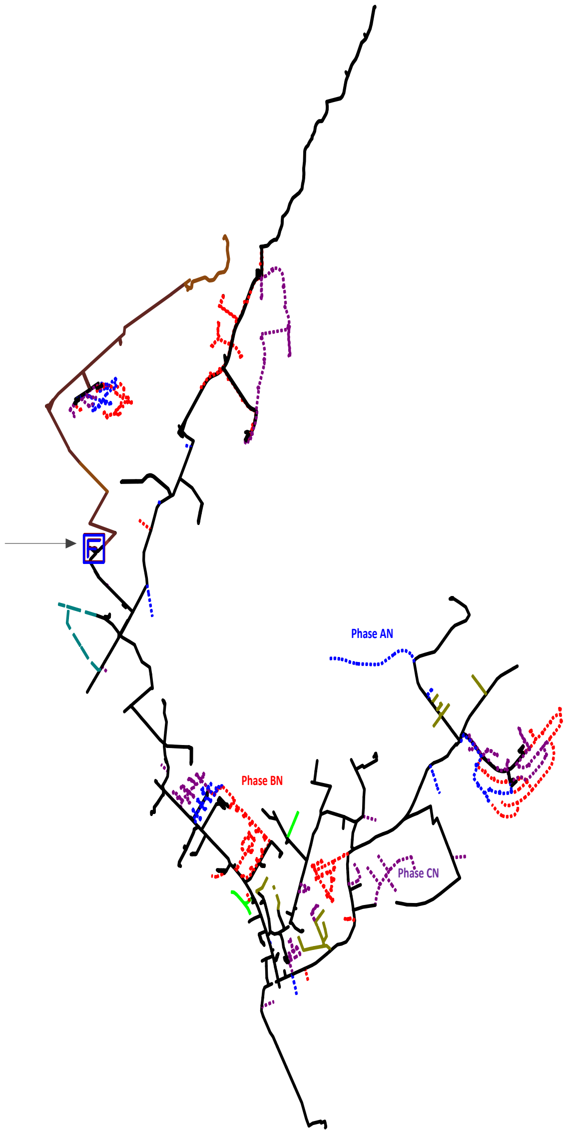
- Results of SANDIA study
  - Largest voltage drop reported was 2.65% due to cloud movement(1.24 MW ramp down)
  - For 2-hour simulation interval, 12 Pst values were reported ranging from 0.04 – 0.79) with resulting Plt of 0.45. Pst and Plt are below the planning limits of 0.9 and 0.7 for Pst and Plt, respectively.
- Conclusion of SANDIA study
  - PV induced voltage fluctuations are gradual/slow to change and would require significant PV plant output changes for flicker issue
  - The study finds no flicker problems on the feeder with a very high PV penetration level on relatively week POI (on the edge of the feeder)
  - The primary benefit using IEEE 1453 method is the significant increase in accuracy compared to the IEEE 519 "snapshot" methodology

# Detailed Study Examples

- Pterra has performed flicker assessment using IEEE-1453 method for utilities in the US with high PV Penetration as well as for large PV and Wind Farm developers:
  - Use a Matlab-based script to process data and drive power flow engine for time series simulations
  - Any power flow simulation tools with time series capabilities can be used with the method
  - Reports are not available publicly



# Questions and Discussion

- Now open for questions and discussion
- Please pass offline questions and comments to Jason Pause at NYS DPS.