Evaluating Flicker Issues in Power Distribution Systems Due to Distributed PV Generation

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1. Introduction

- Flicker is the subjective impression of **fluctuating luminance of incandescent lamps** caused by voltage fluctuations.

- Flicker is mostly caused by **variations in power flow**.

- **Perception of flicker is subjective**, as it may not have the same effect on all observers.

- There is a standardized approach to quantify flicker, based on a statistical model of human reaction to incandescent light variability.

- PV plants can be a source of flicker since the output power may change due to changes in irradiance.
- Irradiance (sunlight) may vary due to cloud movement.
- Varying irradiance causes change in power output of PV plants, eventually causing flicker.
- The paper is based on flicker analysis performed for a PV plant project.

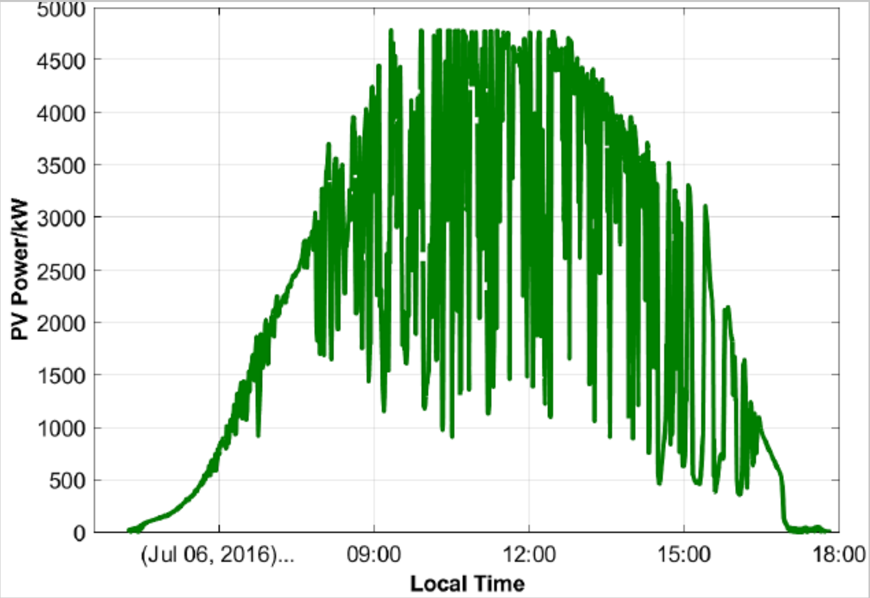


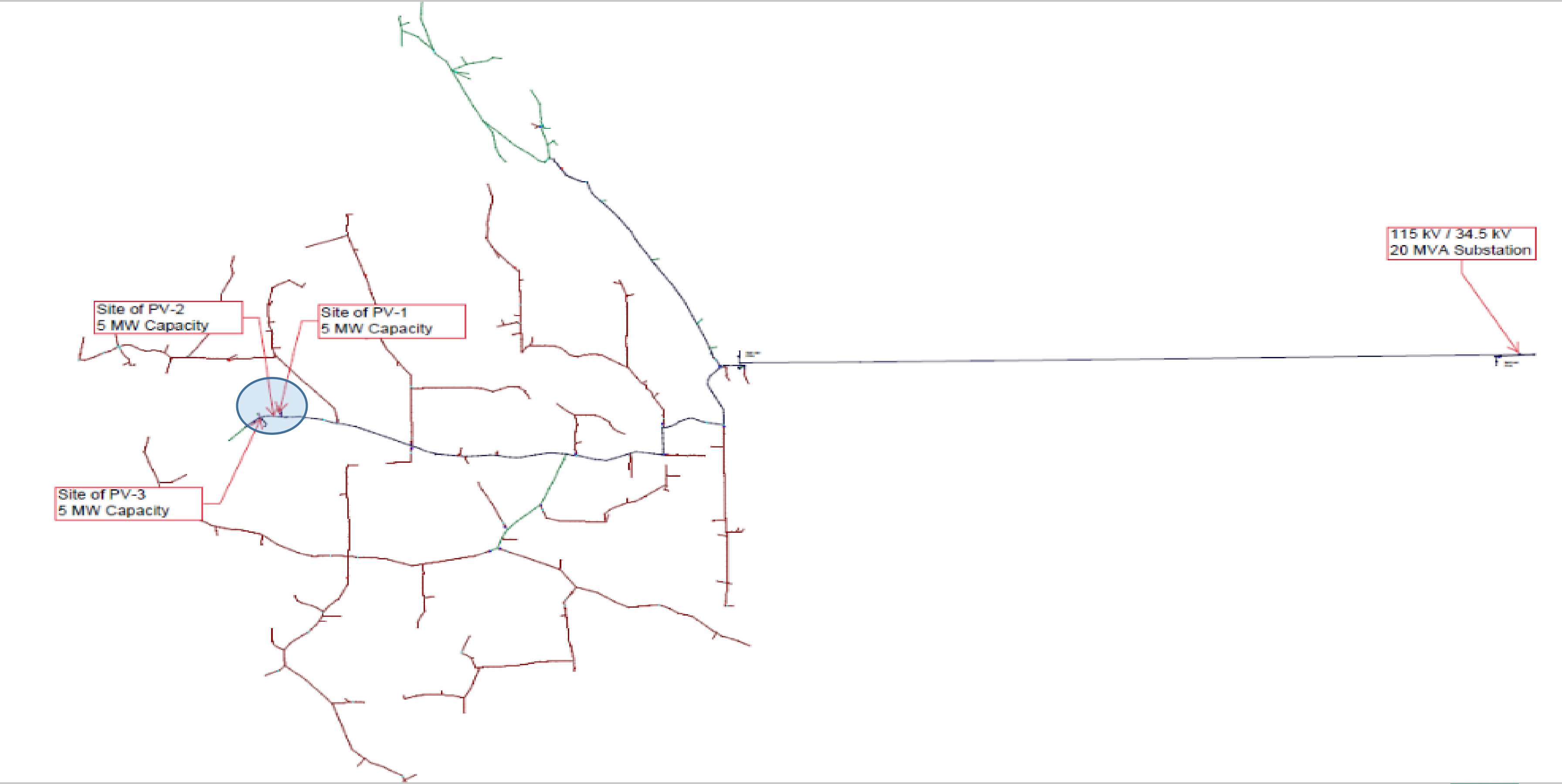
Figure: PV output fluctuation (EPRI)

- The effect of PV plants on flicker can not be accurately determined during planning stages.
- Several methods can be used to estimate impact of PV facilities on flicker.
- This study estimated future flicker levels using three different approaches.
- The methods used are suggested by IEEE Std 1453 and IEC/TR 61000-3-7.

2. Project Background

- A developer proposed to connect three PV plants of 5 MW capacity each (total of 15 MW) to a 34.5-kV distribution system.
- The PV plants are located in close proximity in North East of the U.S.
- Any variation in irradiance may be expected to affect all facilities as they are located next to each other.
- The POI equivalent impedance is

Location	R (ohms)	X (ohms)	Short Circuit MVA
POI	4.9	14.9	76

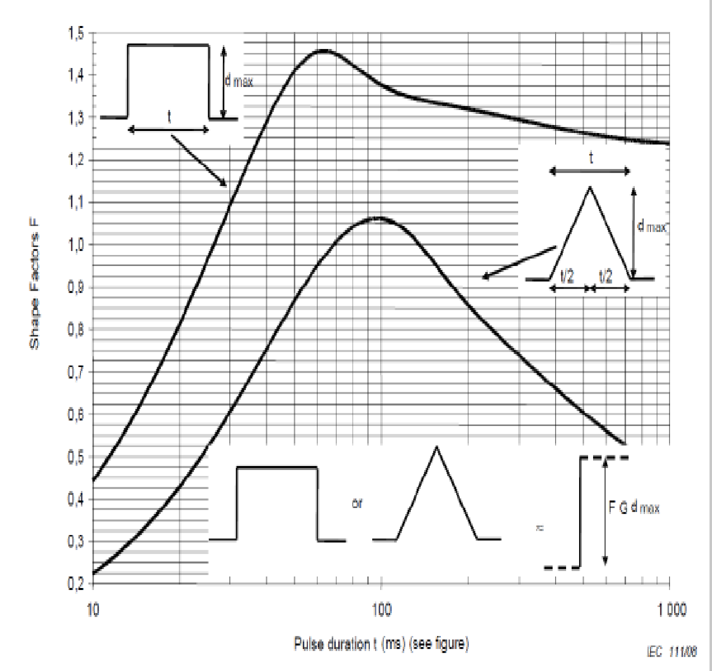

Site of PV-2
5 MW Capacity
Site of PV-1
5 MW Capacity
Site of PV-3
5 MW Capacity
115 kV / 34.5 kV
20 MVA Substation

3. Flicker Study Methodology

- The local utility calculated the severity of the flicker (P_{ST}) based on the equation below:

$$P_{ST} = \left(\frac{d}{d_{P_{ST}=1}}\right) \times F$$

  - F – shape factor
  - d – relative voltage change caused by the planned installation
  - $d_{PST=1}$ – required value of relative voltage change to produce P_{ST} levels of 1



- The study assumed:
  - d_{Pst} = 2.56 (which corresponds to two changes per minute)
  - F = 0.2 (which depends on the shape and duration of the voltage change)

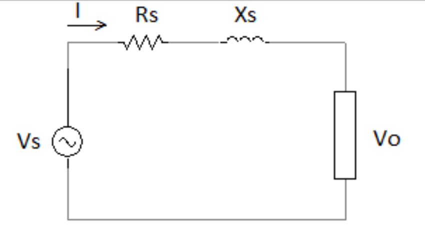
- The relative voltage change (d) caused by power output fluctuations of the PV plants needs to be determined.
- Three methods are used to determine the relative voltage change.
- The flicker analysis considered a 10 MW change in power output of the PV plants and determined the corresponding voltage change.

3.1 Method 1

- The first method calculates the voltage change based on short-circuit ratio.

$$d \approx \frac{\Delta S_i}{S_{sc}}$$

  - ΔS_i – Expected change in apparent power export of the PV plants
  - S_{sc} – Short-circuit MVA of the grid at the POI.
- The equation is derived from a simplified model of a network



- Relative voltage change can be calculated as:

$$d = \frac{\Delta S_i}{S_{sc}} = \frac{10\ MW}{76\ MVA} = 13.2\ \%$$

- And the estimated flicker severity will be

$$P_{ST} = \left(\frac{13.2\%}{2.56\%}\right) \times 0.2 = 1.03$$

- This may not be acceptable in many cases.
- The utility requirement for this interconnection was a flicker severity level of 0.35 or less.

Drawbacks of Method 1:

- The equations is applicable for systems with high X/R ratio. IEEE 1453 recommends X/R ratio greater than 5. It may not provide a reasonable estimate for systems of low X/R ratio.
- More suitable for systems that will cause a significantly large change in reactive power.
- PV plants are expected to have mostly real power output.
- Doesn’t account for other factors that may impact system voltage (e.g. STATCOMS, system topology, regulators etc.).

Advantages of Method 1:

- Simple and easy to use; but the results should be considered as a very conservative estimate.

3.2 Method 2

- The second method calculates the voltage change using the following equation.

$$d = \frac{R_S \times \Delta P + X_S \times \Delta Q}{V_S^2}$$

  - ΔP – Change in real power export of the PV plants
  - ΔQ – Change in reactive power export of the PV plants
  - V_s – System Voltage
  - R_s – Equivalent resistance at POI
  - X_s – Equivalent reactance at POI

- Using Method 2 :

$$d = 4.1\ \%$$
$$P_{ST} = 0.32$$

- The calculation assumes the reactive power export of the plants is zero.
- This level of flicker severity may be acceptable in many cases.

Drawbacks of Method 2:

- Doesn't account for other factors that may impact system voltage (e.g. STATCOMS, system topology, regulators etc.).
- Requires more detailed knowledge of the network compared to Method 1.

Advantages of Method 2:

- Provides a reasonably better estimate (compared to Method 1).
- Easy to use.

3.3 Method 3

- The third method calculates the relative voltage change using a power system analysis software.
- In this study, CYME Power System analysis software was used to determine the voltage change associated with 10 MW power change.
- This approach is expected to provide a much better estimate of flicker severity.

- Using Method 3 :

$$d = 2\%$$
$$P_{ST} = 0.16$$

Drawbacks of Method 3:

- Detailed model of a system is required which may be time and resource intensive to create one.
- Analysis takes longer time.

Advantages of Method 3:

- Provides a much better estimate of flicker severity.

4. Comparison of Results

Factor	Method 1	Method 2	Method 3
Relative Voltage Change (d)	13.2%	4.1%	2%
P_{ST}	1.03	0.32	0.16

5. Conclusions

- Flicker severity due to PV plants using Method 1 may be overly conservative and misleading.
- Method 1 may provide a reasonable flicker estimate in systems with high X/R ratio and the change in power flow is mostly reactive.
- Method 2 may provide a reasonable estimate if there is no other choice.
- Method 3 provides a more accurate estimate of flicker severity.
- Utilities may use overly simplified methods of calculating flicker that can potentially block credible PV interconnections

- **References**

- IEEE Std 1453-2015, “IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems”.
- IEC/TR 61000-3-7, “Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems”.
- Electric Power Research Institute (EPRI), “Flicker Measurements at Photovoltaic Plants”. [Online]: https://www.epri.com/#/pages/product/000000003002011897/?lang=en.
- IEC/TR 61000-4-15, “Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 15: Flickermeter – Functional and design specification”.
- Central Station Engineers of the Westinghouse Electric Company, “Electrical Transmission and Distribution Reference Book”, Westinghouse Electric Corporation, East Pittsburgh, PA, Fourth Edition.