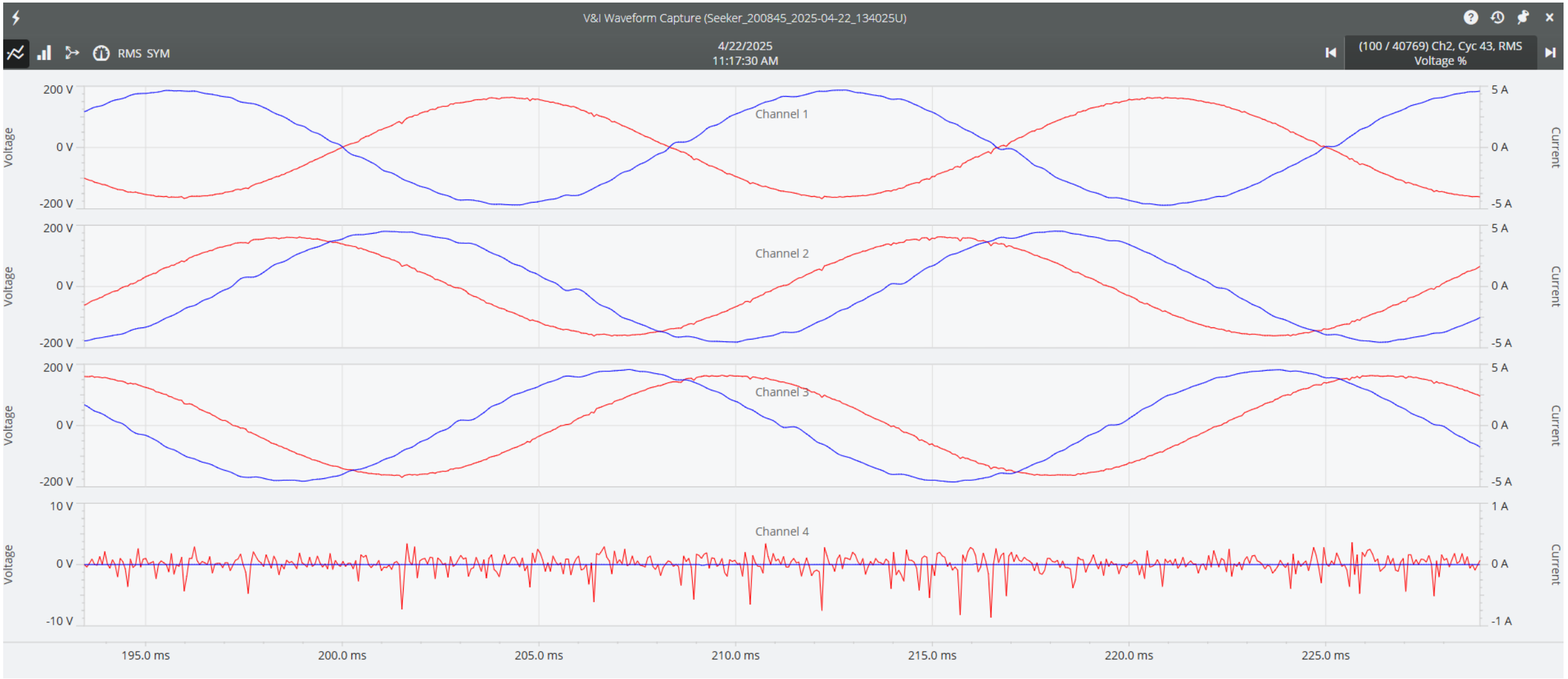
LED Flicker Complaints from a rural feeder with multiple PV Plants

Scenario Description

- **35kV Feeder with 6 PV Plants**
- **Total solar 22.78 MW**
- **Substation source 60.471 MVAsc**
- **Three points of interconnection (POIs)**

Parameters	1	2	3	4	5	6
MW	5.00	5.00	2.00	4.98	3.80	2.00
MVA Fault at POI	58.200	58.200	42.366	42.366	40.155	40.155
Dist from Sub. (mi)	1.50	1.50	7.44	7.44	9.94	9.94

Waveform Capture – PMI Seeker installed at PV Site



Red – Voltage
Blue - Current

IEEE Standard 2800, Annex C, "System Strength Definition"

The term system strength, or system stiffness, typically means one of two things:

a) System inertia, or df/dP, which classically refers to the ability of the system to resist changes in frequency.

b) Source impedance strength, which refers to how high the impedance is to the grid voltage source as seen from some point on the system relative to the size of a generator connected at that point. A "weak" system has a high source impedance.

Application of IEEE Standard 2800, Annex C, "Inverter stability and system strength"

This annex defines four methods to assess stability and potential incompatibility with the feeder operation, such as voltage impact.

Table C.1—Comparison of system strength metrics

Metric		Simple calculation using short-circuit program	Accounts for nearby inverter-based equipment	Provides common metric across a larger group of IBR	Accounts for weak electrical coupling between plants within larger groups	Considers non-active power inverter capacity[a]	Able to consider individual sub-plants within larger groups
SCR	Short-circuit ratio	Yes	No	No	No	No	No
CSCR	Composite SCR	Partial	Yes	Yes	No	No	No
WSCR	Weighted SCR	Partial	Yes	Yes	Partial	No	No
SCRIF	Multi-infeed SCR	No	Yes	N/A	Yes	Yes	Yes

[a] For example, static synchronous compensators (STATCOMs) or partial power IBRs. Note that any of these can be calculated using MW (Equation [C.6]) or MVA (Equation [C.7]) to consider non-active power inverter capacity as desired.

SCR Ratio Results for 6 plants, 3 POIs

Plant Location Short Circuit Ratio (SCR)

$$SCR_{POI} = \frac{SCMVA_{POI}}{MW_{IBR}}$$

- **Site 1 ratio = 5.82**
- **Site 2 ratio = 6.07**
- **Site 3 ratio = 6.92**

Composite Short Circuit Ratio (CSCR)

$$CSCR = \frac{CSC_{MVA}}{MV_{IBR}}$$

- **CSCR = 2.65**

Weighted Short Circuit Ratio (WSCR)

$$WSCR = \frac{\sum_i^N \left(SCMVA_i \times P_{RMW_i} \right)}{\left(\sum_i^N P_{RMW_i} \right)^2}$$

- **WSCR = 2.14**

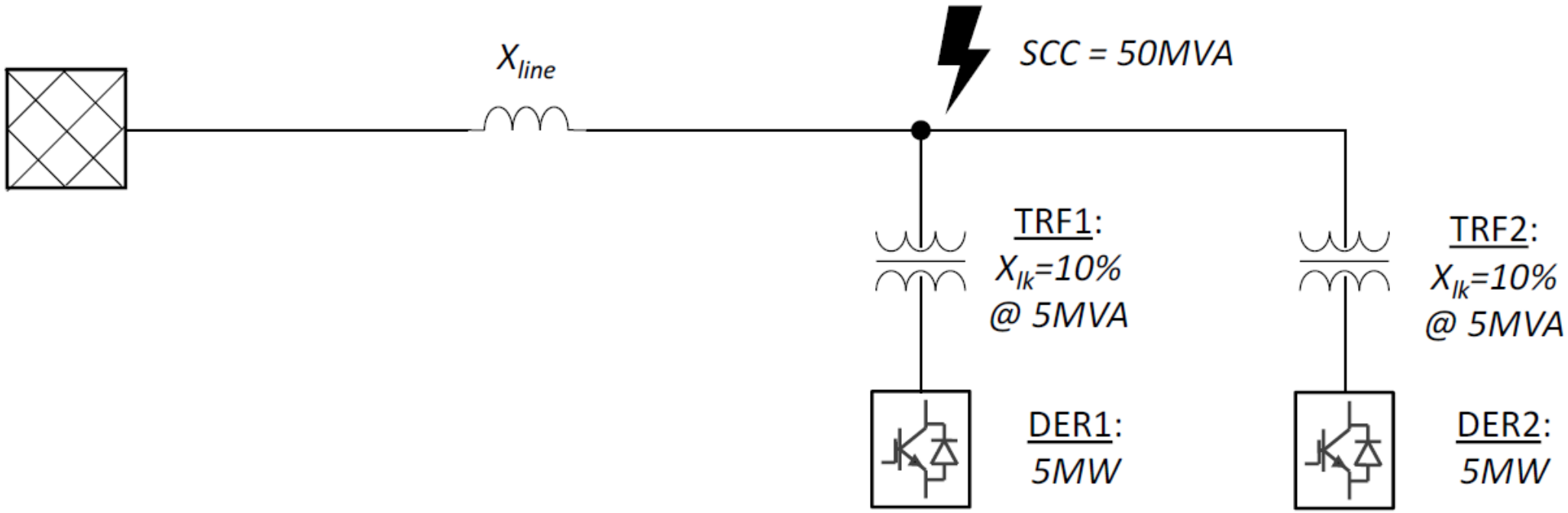
Note that feeder stiffness at each site location (~6) is significantly higher than the weighted average ratio of ~ 2 and a composite using substation MVAsc at 2.6 is also more than the weighted average.

Calculation of Short Circuit Ratio for Multiple DER Cases

Wei Ren

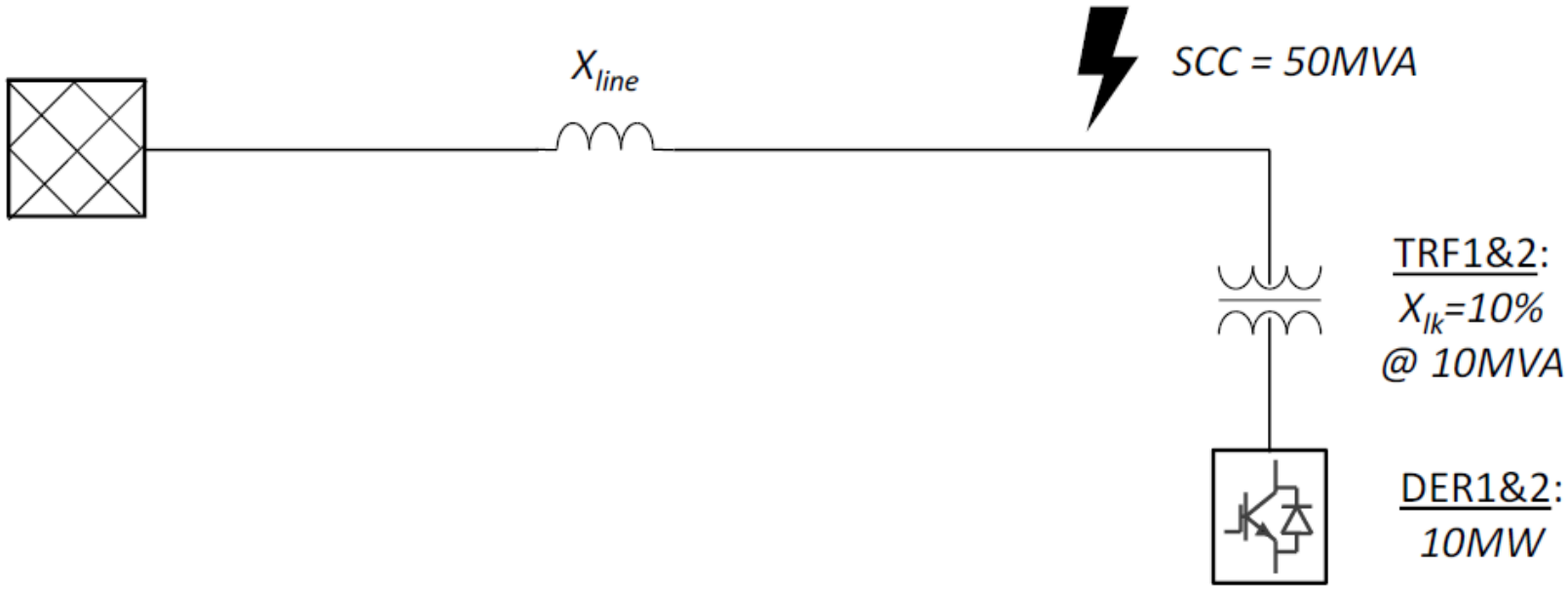
4/4/2025

A Simple Circuit with Two DERs



Assuming Both DERs Are Identical

SCR Calculation from Circuit Equivalence



Using 10MVA as the per-unit base for the following calculations:

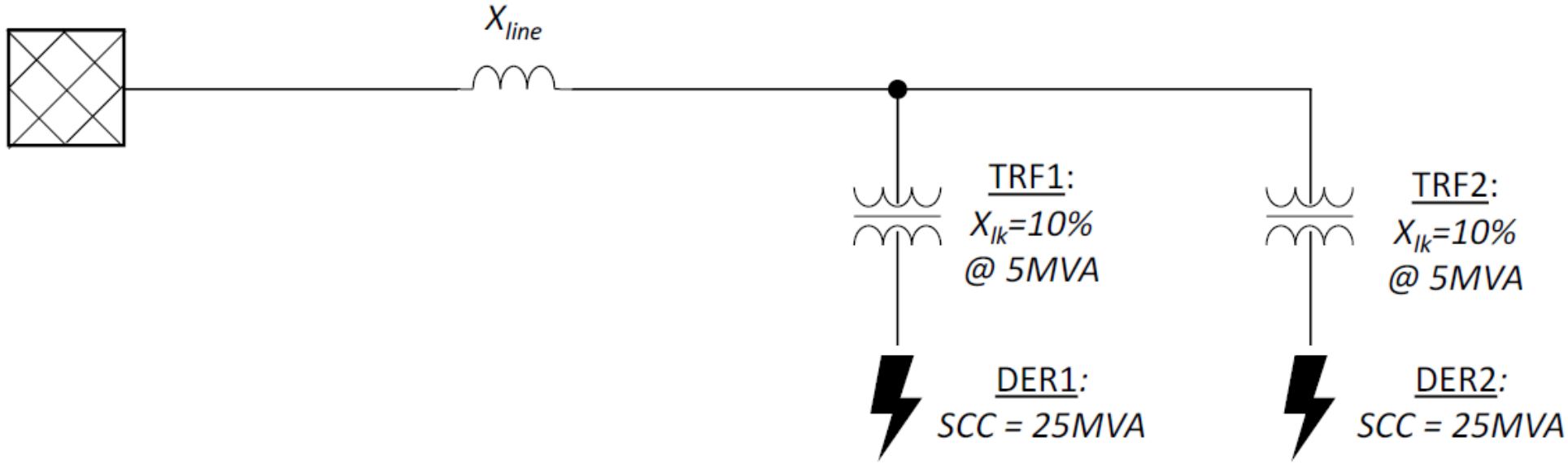
$$X_{line} = \frac{1}{50MVA} \cdot 10MVA = 0.2pu\ (@10MVA)$$

$$X_{Total} = X_{line} + X_{TRF1\&2} = 0.2pu + 0.1pu = 0.3pu$$

$$SCR = \frac{1}{X_{Total}} = \frac{1}{0.3pu} = \mathbf{3.33}$$

This SCR is the "Should-Be" Value (=3.33)

SCR Calculation using Texas Weighted Method



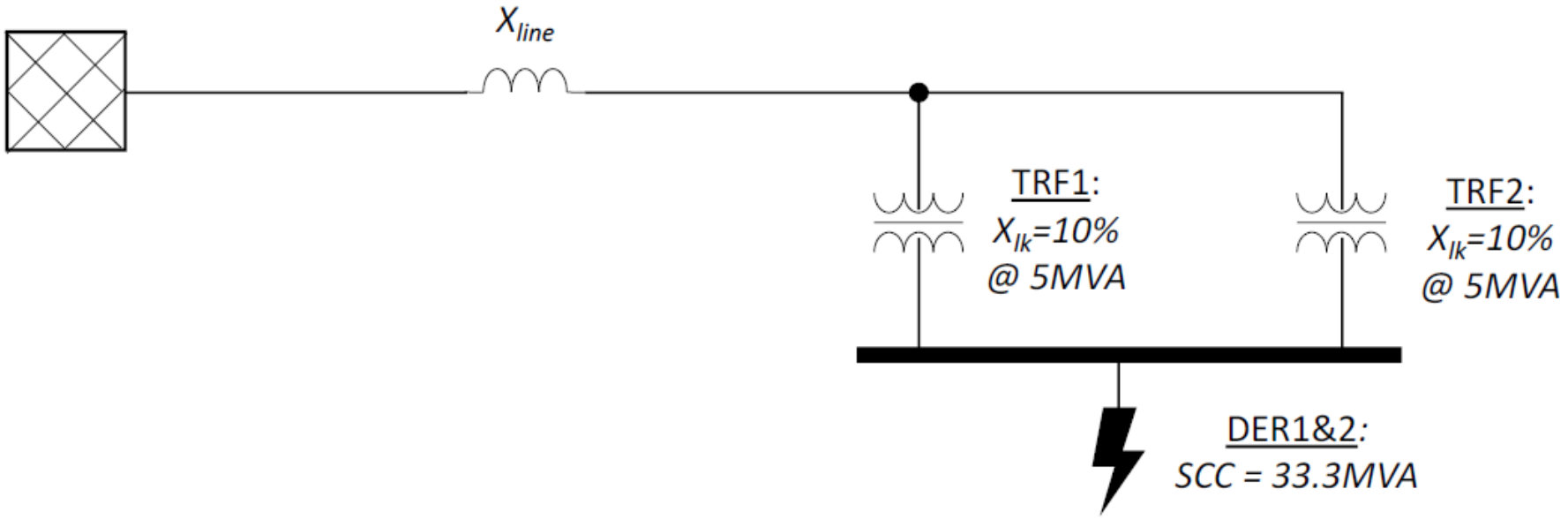
WSCR Yields Over-Conservative Result:

$$WSCR = \frac{\sum_i^N SCMVA_i \cdot P_{RMWi}}{(\sum_i^N P_{RMWi})^2}$$

$$= \frac{25MVA \cdot 5MW + 25MVA \cdot 5MW}{(5MW + 5MW)^2} = \mathbf{2.5}$$

With More Paralleled Branches, WSCR Can be Too Small

SCR Calculation using GE Composite Method



CSCR Creates a Common Bus that Connects All DERs Together

$$CSCR = \frac{CSC_{MVA}}{\sum_i^N P_{RMWi}}$$

$$= \frac{33.3MVA}{5MW + 5MW} = \mathbf{3.33}$$

CSCR Does a Much Better Job in Matching the "Should-Be" Value

Conclusions

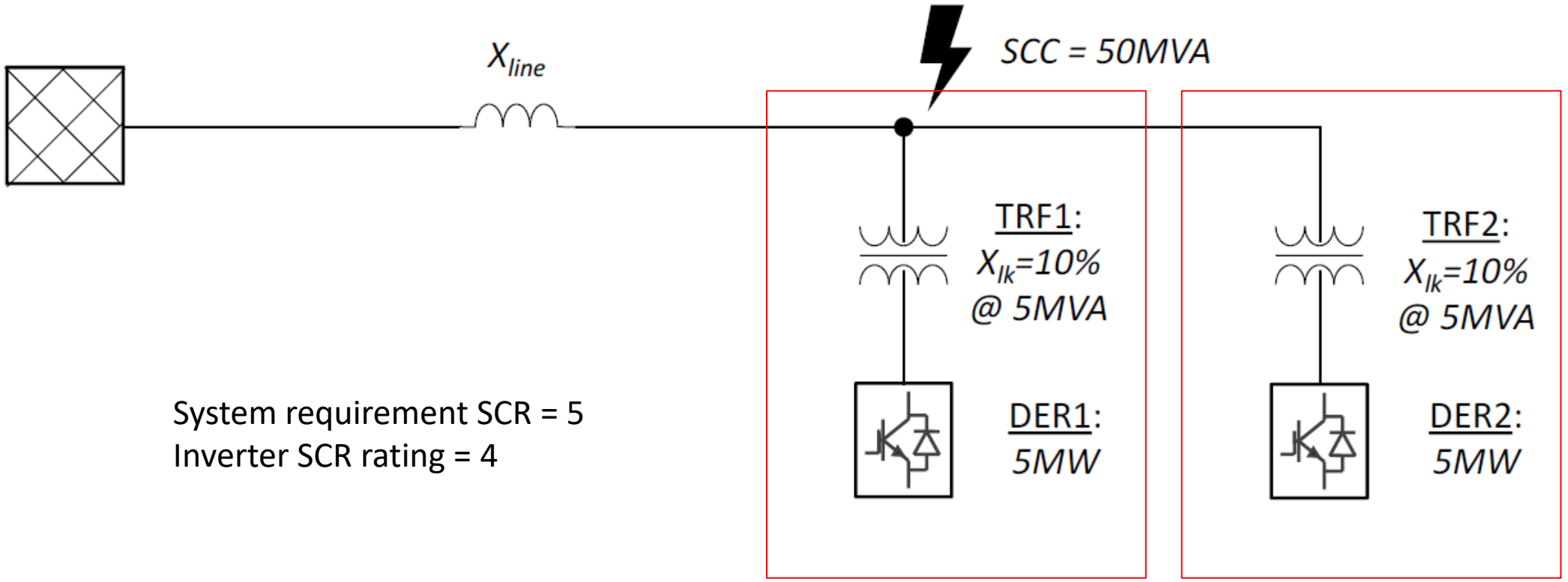
- The Weighted SCR calculation (WSCR), in a complex network with common and separate branches, tends to over-estimate system impedance and yield erroneously low WSCR value

- GE's Composite SCR calculation reserves the network impedance equivalence and leads to more accurate CSCR result

A Simple Circuit with Two DERs

Existing System requirement
SCR = 5
Inverter SCR rating = 4

Future System requirement
SCR = 3.33
Inverter SCR rating need to be below 3.33



System requirement SCR = 5
Inverter SCR rating = 4

Assuming Both DERs Are Identical

Why focus on the Short Circuit Ratio (SCR) and X/R?

- Not all inverters can support a weak grid
  - Sungrow
    - PV inverter minimum SCR 1.1 - 5.4 depending on the model
    - Energy Storage minimum SCR 1.5
  - Sunny (SMA)
    - Claims a SCR low as 1.0 for both the (Sunny Central) and BESS (Sunny Central Storage).
  - Other Inverter Manufacturers
    - As high as 4.0
- The X/R is also important. If it is significantly below 5, the inverter's SCR rating may not be valid
- Specify the inverter SCR not just based existing system conditions but future system conditions. The SCR requirements of the feeder will be more stringent if more inverter-based resources are connected to the feeder.
- NYSEG/RGE recommends the PV inverter to be rated with an SCR in the 1.0 - 2.0 range and X/R of not more than 5.

Ameren Illinois Distributed Energy Resource Interconnection Policy Public Facing Guide

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4.5. Stability Analysis Requirements: These requirements apply to sub-transmission interconnection studies. A short-circuit ratio (SCR) metric is applied to determine the need for a dynamic analysis. The SCR at the inverter terminals of the DER must be greater than 3 during both normal and contingency system conditions. When the SCR is below the limit, the developer shall provide Ameren Illinois proof (1) from the inverter manufacturer that the inverters can operate at the lowest observed SCR value and (2) that the DER remains stable under all system conditions. When the SCR is below the limit and other electrically close inverter-based resources are present, then Ameren Illinois requires an electromagnetic transient (EMT) analysis to determine impacts on the EPS. All requested forms of proof and additional studies must be submitted and completed before continuing the interconnection study process.

Potential Solution to mitigate PQ issue associated with a weak grid (NERC Reliability Guideline December 2017)

Short Circuit Ratio (SCR) = Short Circuit MVA at common bus / MW sum of nominal power rating of the inverter-based resource.

- Synchronous Condenser – Supplies fault current, increases system inertia, voltage capability and voltage stability.
- Plant Control Changes – Adjusting the time constant and gains to reduce risk of unstable response.
- Converter Control Changes – Modifications to control parameter values and/or modifications to the control structure.
- Reduction in Plant Capacity or Power Output – Increase the SCR.
- Transmission/Distribution Reinforcement – Line reconductoring, new transmission circuits, new or larger transformer can increase the SCR.
- FACT Devices – SVC and Statcom help control system voltage by providing dynamic reactive support. Have fast control loops that can interact with inverter-based resources on weak grids and are limited in their fault current contribution.

Notes: NERC Integrating Inverter-Based Resources into Low Short Circuit Strength System Reliability Guideline December 2017