PV Penetration in the Western Cape

Eskom, CoCT, U Stel., UCT, CPUT workshop: Oct 2018

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Background

- Increased installation of PV systems, globally as well as in SA.
- Projected increase of the PV share in the energy mix (also reflected in IRP 2017)
- Concern over the implications for networks, the severity, and mitigation are trending topics of debate

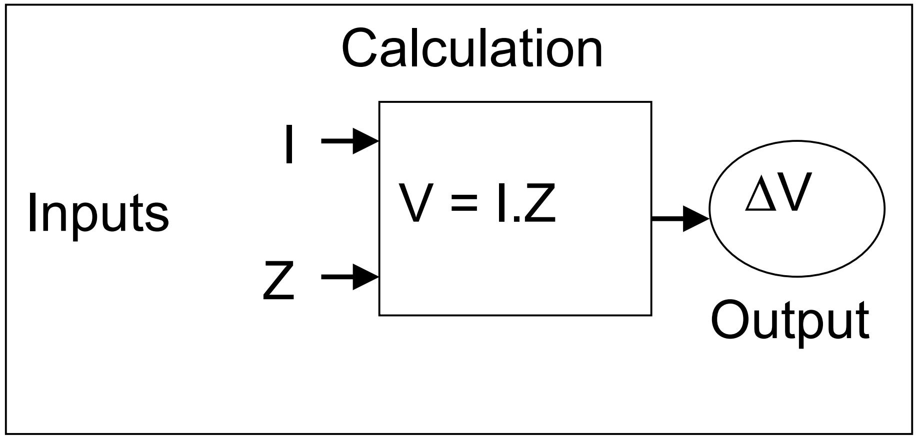
Research Objectives

1. Determine the technical performance of distribution networks with high PV penetration

2. Develop a methodology to assess the PV hosting capacity of LV networks

3. Determine the limits for household injections

System model



Input and solution technique:

Inputs	Approach	Techniques	Model
Uncertain	Probabilistic	Statistical analytical	Pdf’s
		Simulation	Monte Carlo

Load flow (LF)

Deterministic (DLF)

Use defined, specified and non-random values to specify system inputs.

Based on mean ADMD/hh at system MD.

Uses empirical factors to account for uncertainty.

Probabilistic (PLF)

System inputs defined through pdfs/cdfs.

Explicitly accounts for uncertainty and variability.

Reflect uncertainty in system output states (risk).

Better awareness of actual network conditions.

Probabilistic framework

Objectives:

1) cater for load stochasticity
2) include the variability of PV-DG power production
3) simulate the uncertainty in the location and capacity of future PV-DG installations

Components:

- Probabilistic load flow tool – Extended Herman Beta (HBE) transform – caters for (1) and (2)
- Stochastic simulator – Monte-Carlo Simulation (MCS) – caters for (3)

Scope of HBE-transform

Loads

- Current models @ any power factor.
- P,Q @ deterministic pf; (perfect correlation $\rho_{P,Q}$=1); other correlations under testing.
- Balanced - ($\rho_{A,B}$=1, $\rho_{A,C}$=1, $\rho_{B,C}$=1); others being tested.
- Unbalanced.
- Correlations DG-DG; L-L; L-DG

AND: **DG** @ any pf.
Shunt capacitors.

FOR: LV, MV, HV
1- and 3-phase 2-, 3- or 4-w feeders.

Input – Transform – Output

System Inputs

- Feeder Electrical Properties
- Feeder, load and DG models

HBE Transform

- Statistical transform based on the method of moments

System Outputs

Statistical description (within risk) of:

- Voltage drop / bus voltages
- Line currents

This feeder model

Feeder type

3-phase 4-wire, no compensation technology

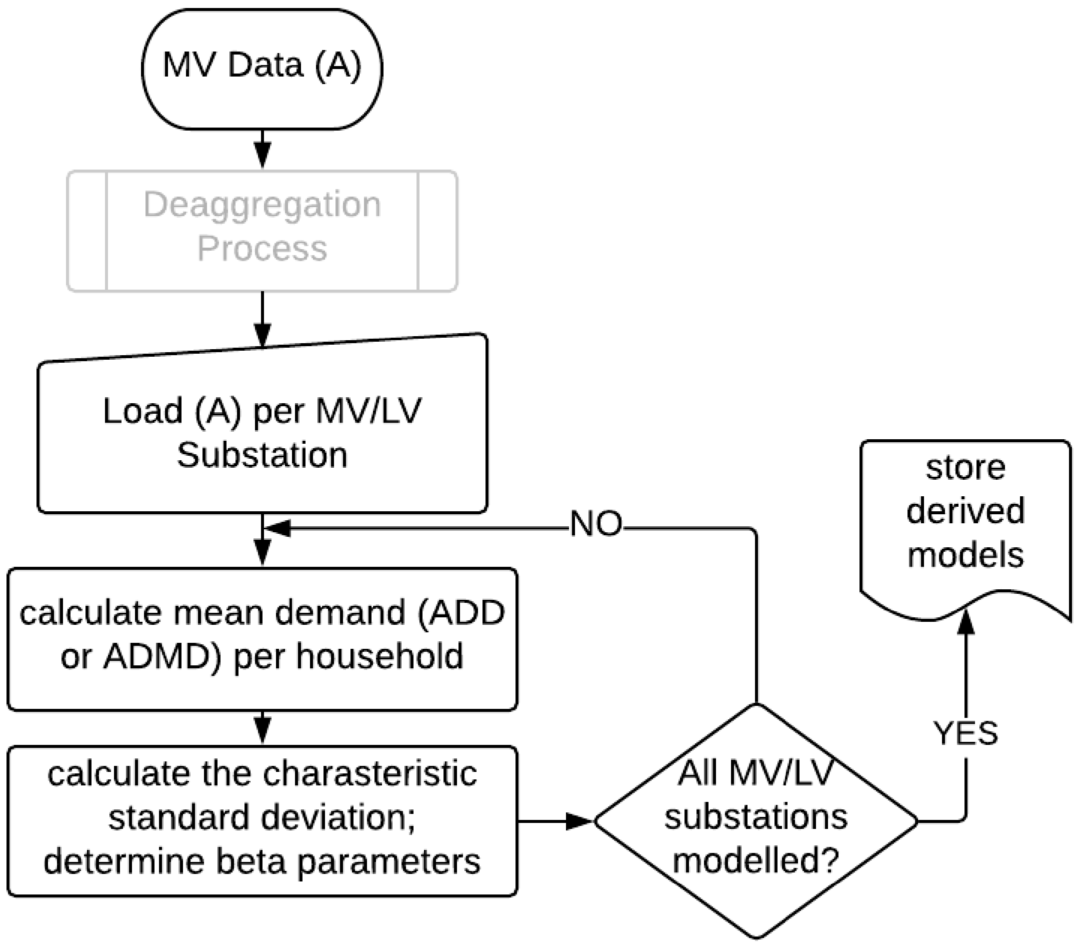
Topology

Parameters of sections between nodes

Allocation of loads at node/phase

Kiosk Name		Branch Properties						Customer Allocation (to Kiosk)		
From node	To node (Kiosk)	Conductor Type	Length [m]	R [Ω]	X [Ω]	Y/2 [℧]	Current Rating [A]	A	B	C
4	0	Al120	149.53	0.0421	0.0128	--	219	2	2	1
2	1	Al35	83.8	0.0791	0.0075	--	108	1	2	2
3	2	Al70	64.73	0.0308	0.0056	--	158	2	1	1

Derivation of Statistical Load Models



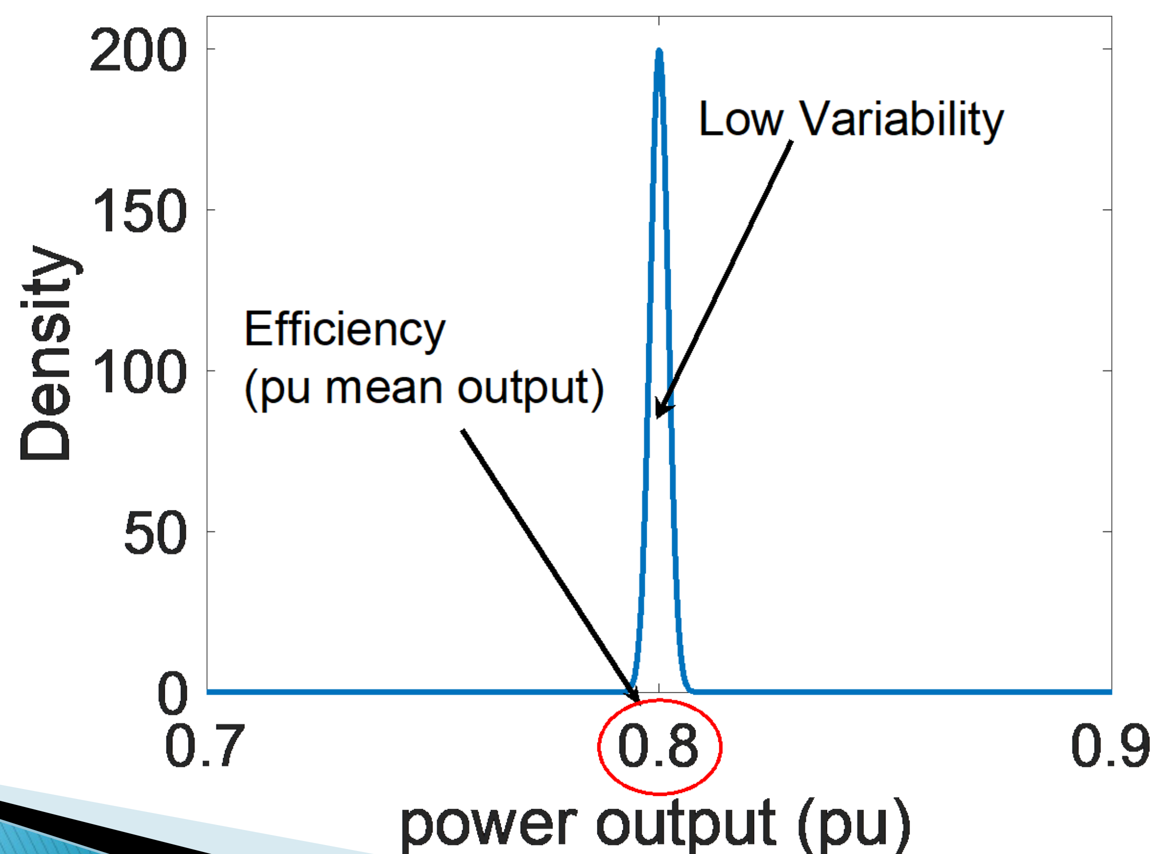
Derivation of Statistical Load Models

Trfmr Name	ID	Rating [kVA]	Deaggregated Group Load Characteristics			Statistical Load Characteristics per household						
			Allocated Summer Demand [kVA]	Allocated Winter Demand [kVA]	Total Cust.	Summer ADD [kVA]	Winter ADMD [kVA]	CB limit [A]	Summer		Winter	
									α	β	α	β
Sunset Rocks		500	55.64	145.84	36	1.546	4.051	80	1.083	11.812	1.445	5.118
Fisherman's Bend		500	97.67	256.00	55	1.776	4.654	80	1.173	10.980	1.420	4.194
Leeukoppie		500	80.51	211.03	45	1.789	4.690	80	1.178	10.932	1.418	4.146
Oakburn		315	41.21	108.01	30	1.374	3.600	80	1.003	12.431	1.446	5.945
St. Mark's		500	72.03	188.80	46	1.566	4.104	80	1.092	11.738	1.444	5.029
Llandudno		800	80.51	211.03	53	1.519	3.982	80	1.072	11.908	1.446	5.237
Hargrave		315	101.22	265.30	44	2.300	6.030	80	1.317	9.217	1.296	2.658

PVDG model

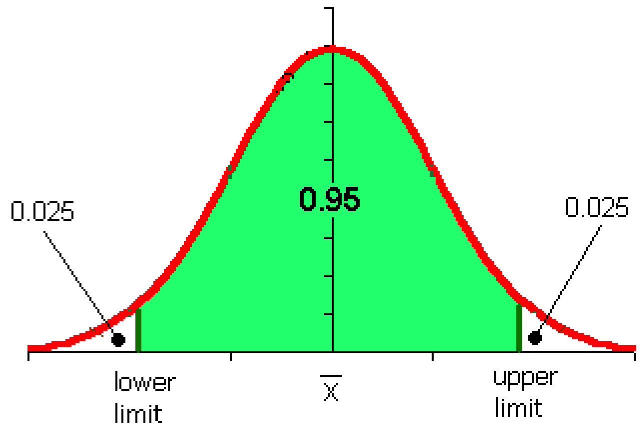
- calculation based on extreme case:

  PV-DG_{max} and coincident $Load_{min}$



Interpretation of Outputs

- 2.5 % risk on both tails (lower tail – passive feeders; upper tail – active feeder)

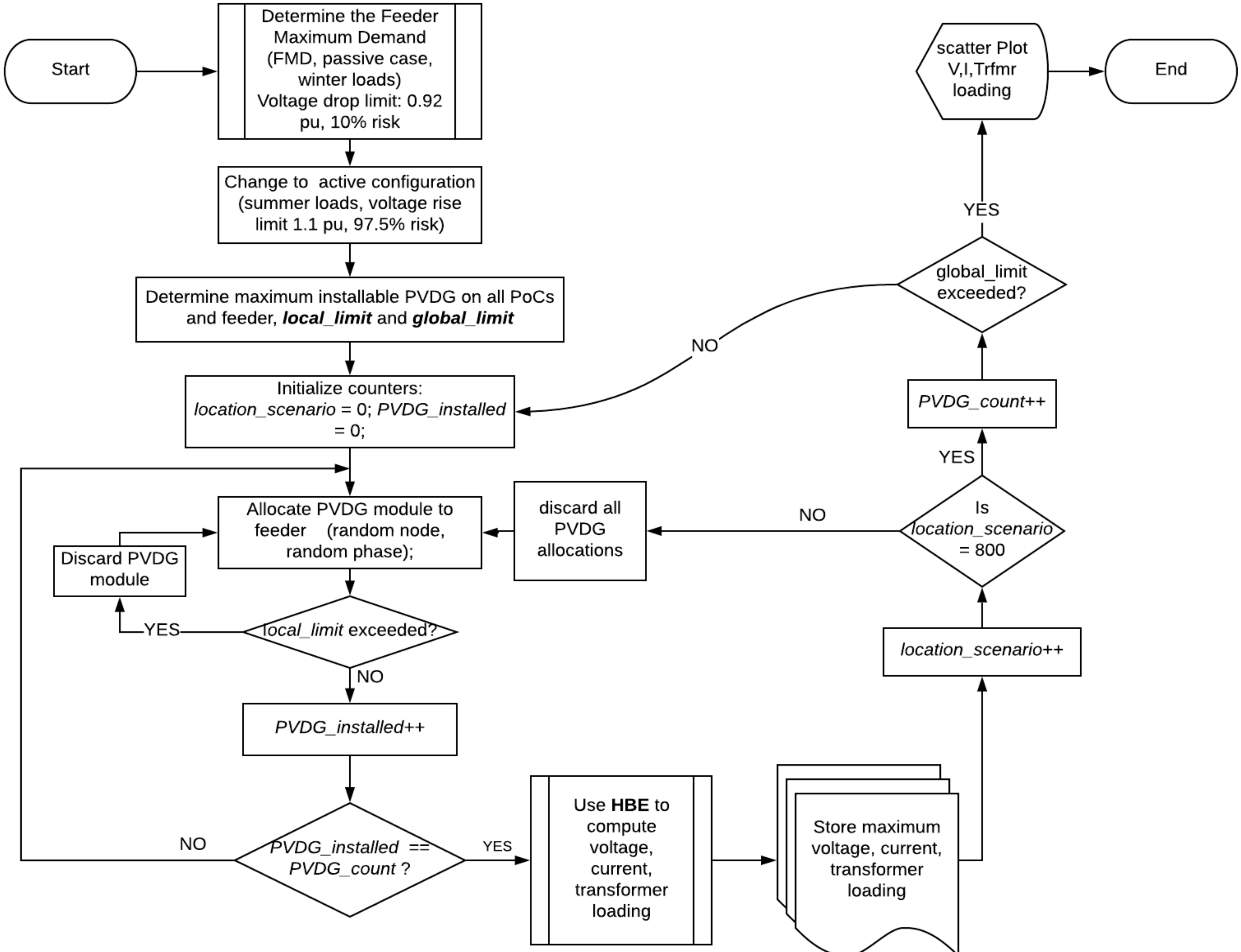


Variable	Lower Limit	Upper Limit
Voltage	0.92	1.1
Current	--	1.0
Trfmr Loading	-1.00 (rpf)	1.00

Stochastic Simulator - MCS

- Based on random number generation and sampling
- Random placement to node
- Random phase allocation
- Placement constrained by:
  - circuit breaker size
  - available roof-space
- 800 scenarios (runs)

Stochastic-PLF Methodology



Definition of penetration (%)

- % penetration = $\frac{\sum_{i=0}^{N} PV_{rated_i}}{FMD} \times 100\ \%$

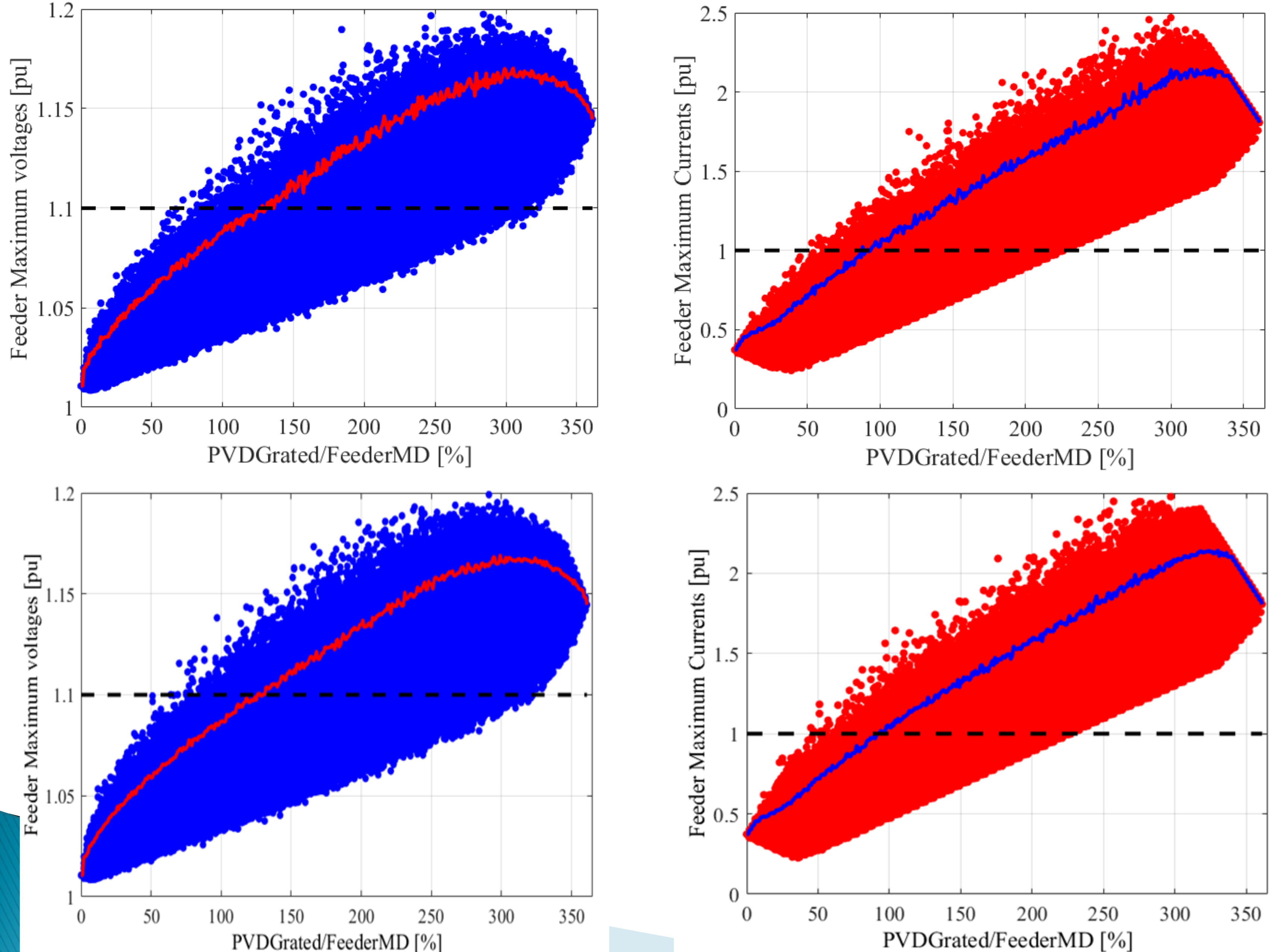
- FMD - Feeder Maximum Demand:

  The maximum load that the feeder can supply without violations of either voltage or thermal conditions.

Results (800 or 2000 scenarios)

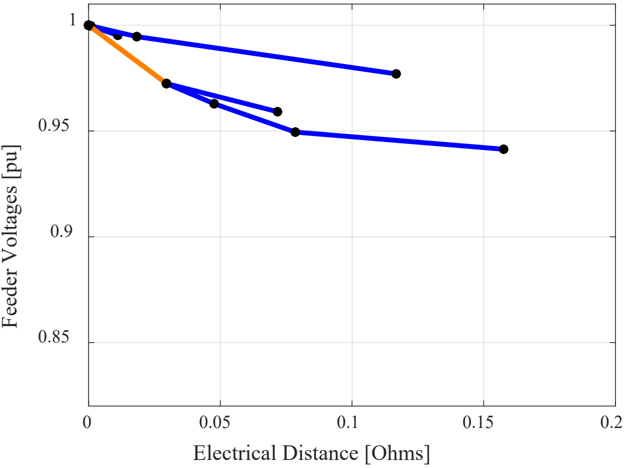
800

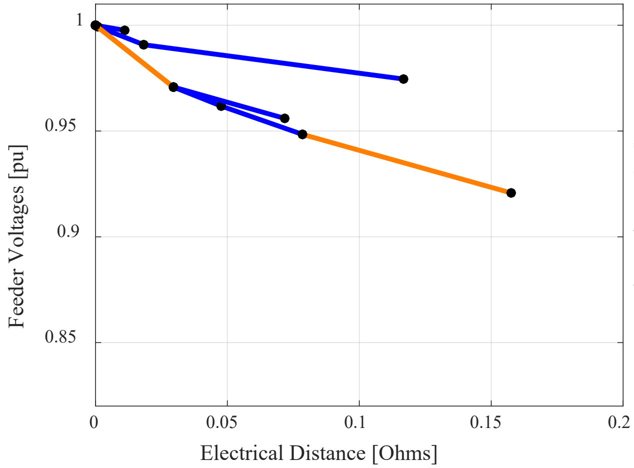
2000

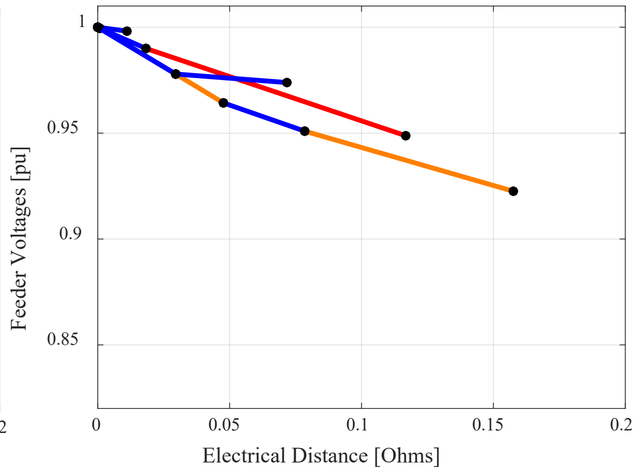


Results – voltage, current, total load

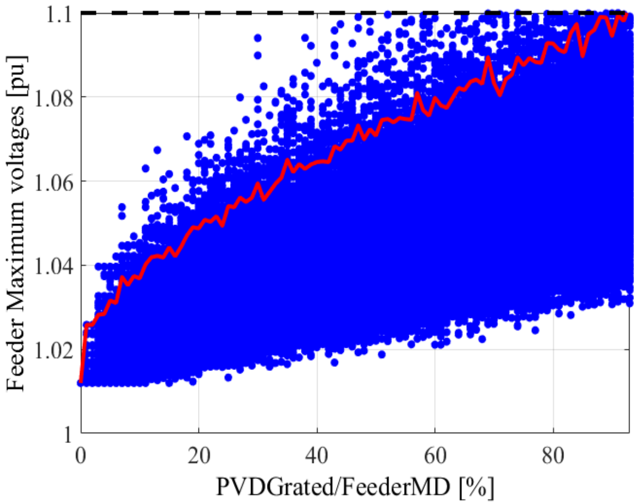
Passive case: Phases A, B, C



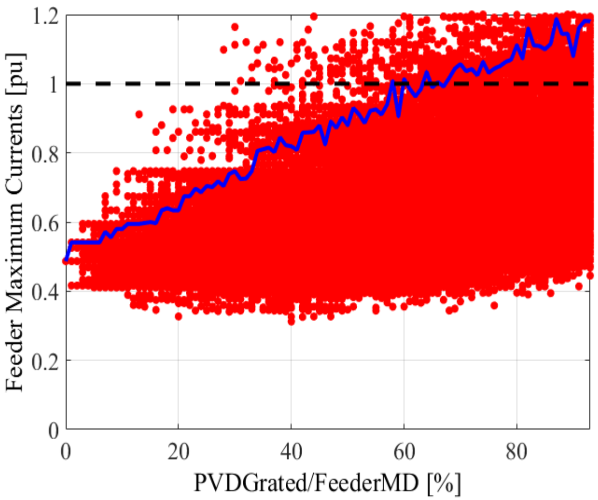




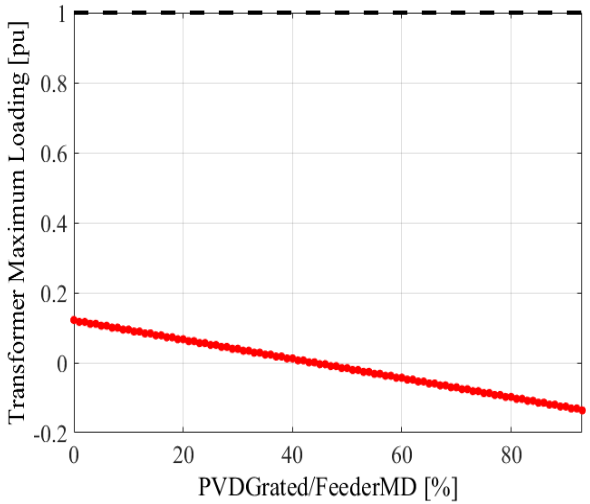
Active case: Max. Voltage



Max. Current



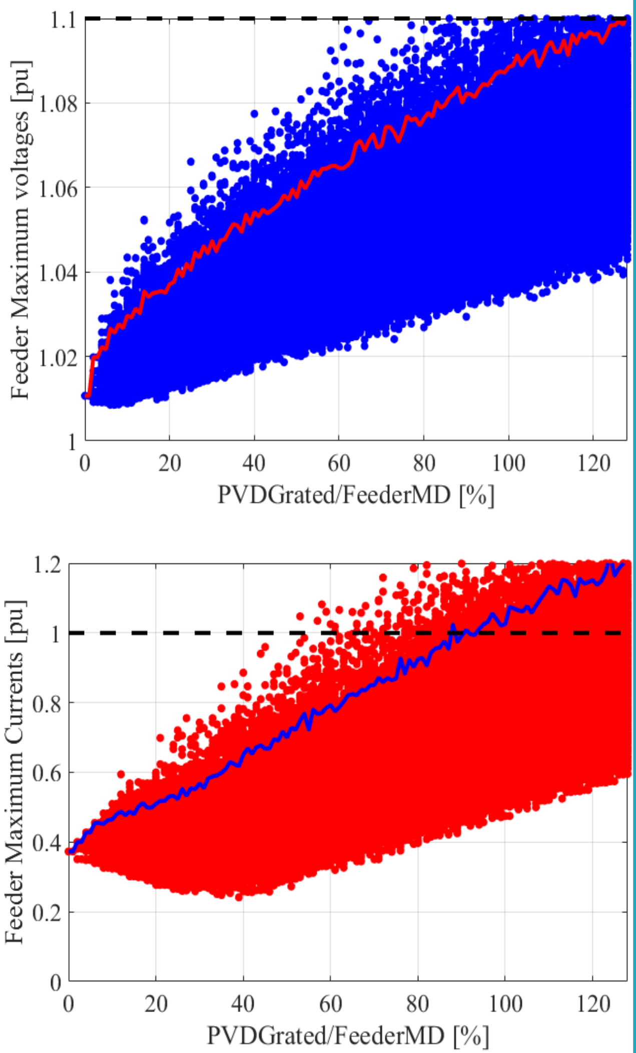
Transformer Loading



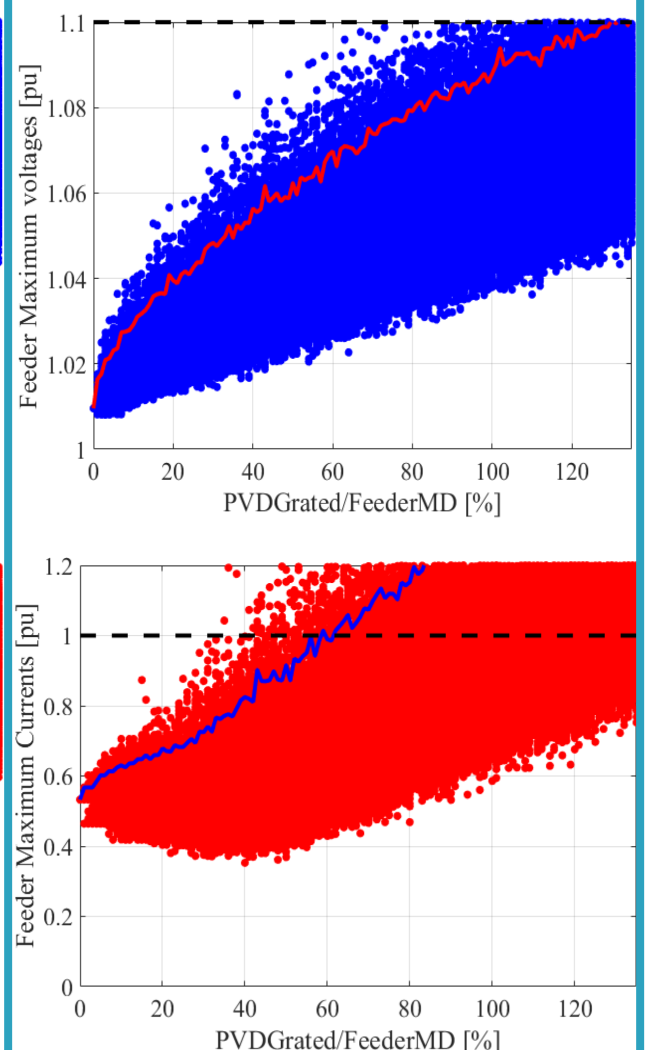
Sunset Rocks feeder

Active feeder results

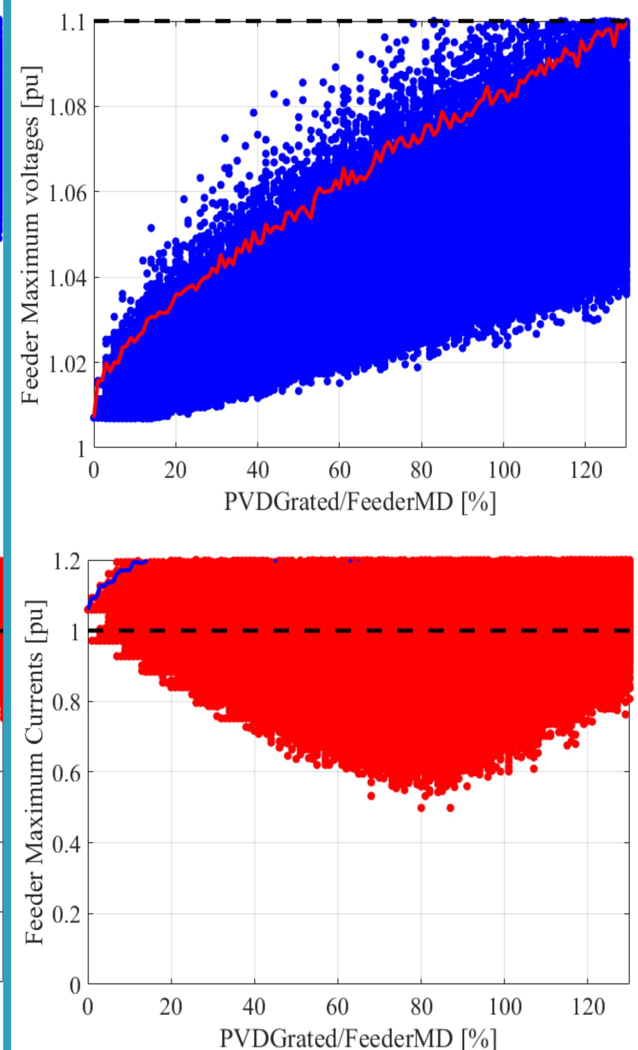
Oakburn



Fisherman's Bend



Hargrave

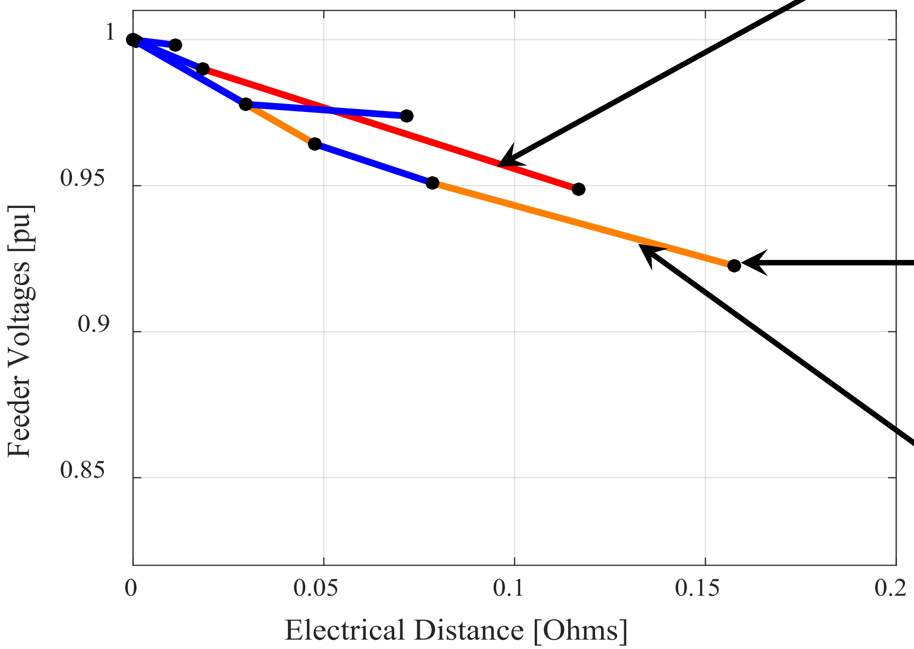


Interpretation of results

Violation of limits:

- Passive feeder
  - **voltage drop** (usually at end), and
  - **thermal** rating on any section
- Active feeder
  - **voltage rise** at any node, and
  - **thermal** rating on any section
  - **transformer** loading
  - **losses**

Voltages, currents on passive feeder

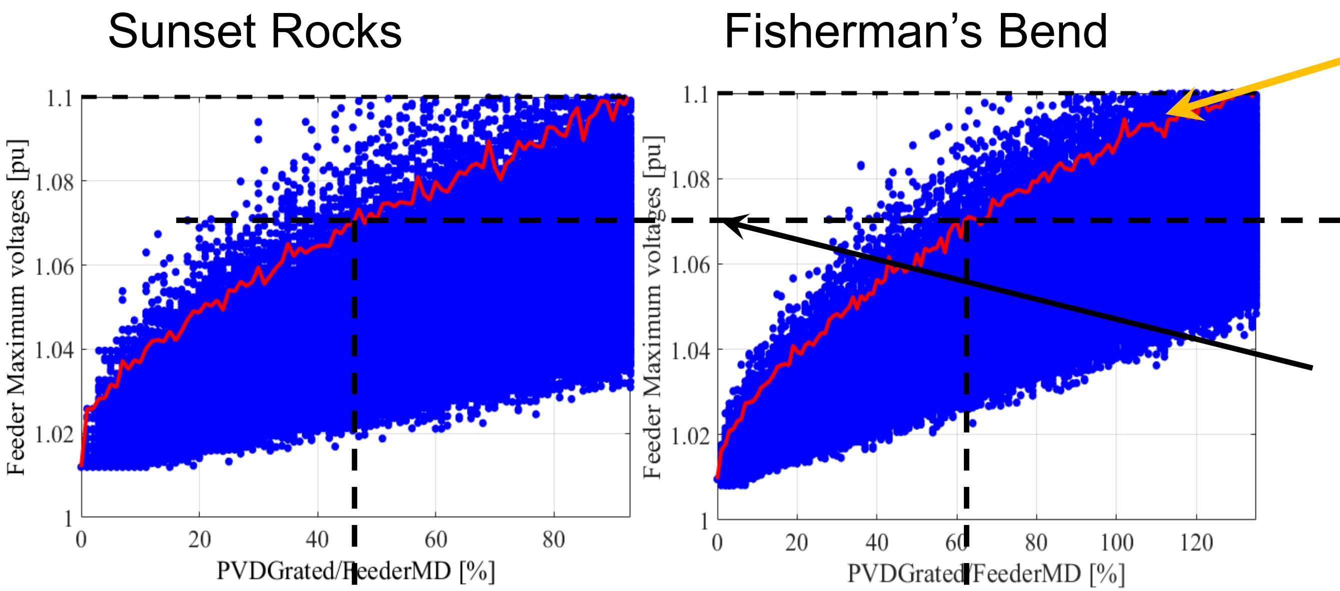


Branch current limit exceeded

Lowest V on this phase; voltage down to 0.92pu

Branch current close to limit

Voltage rise at any node



95% limit of confidence

Limit LV voltage rise to 7% above nominal; allows for correlated MV voltage rise 3%

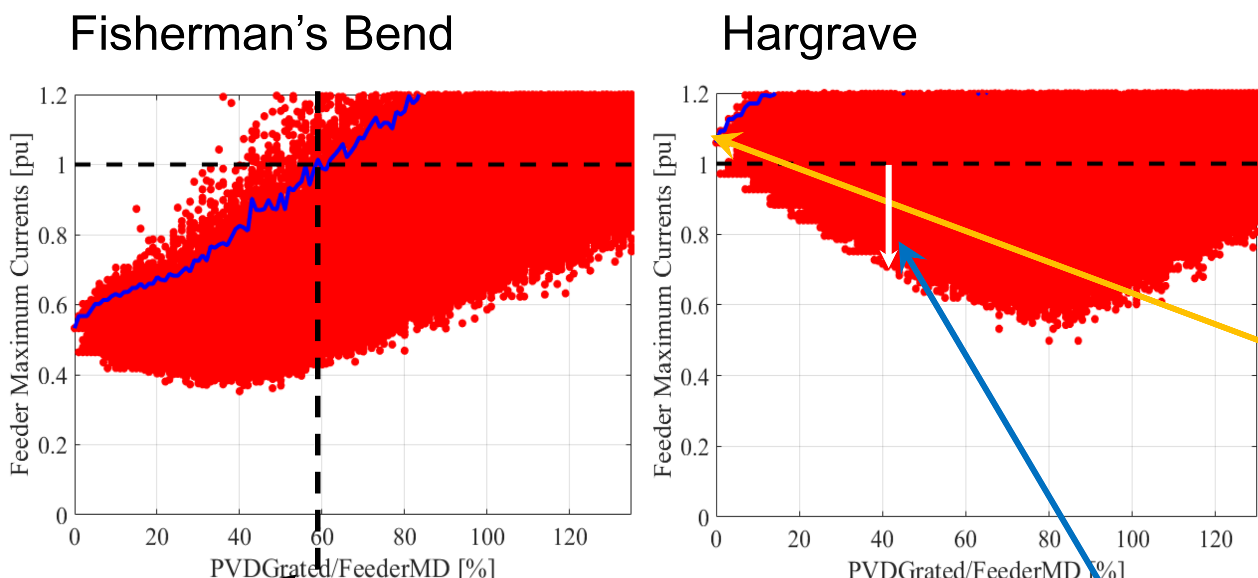
45%

62%

PV penetration limit as % of feeder MD

(with 5% risk of voltage violation)

Current in active feeder



Thermal limit

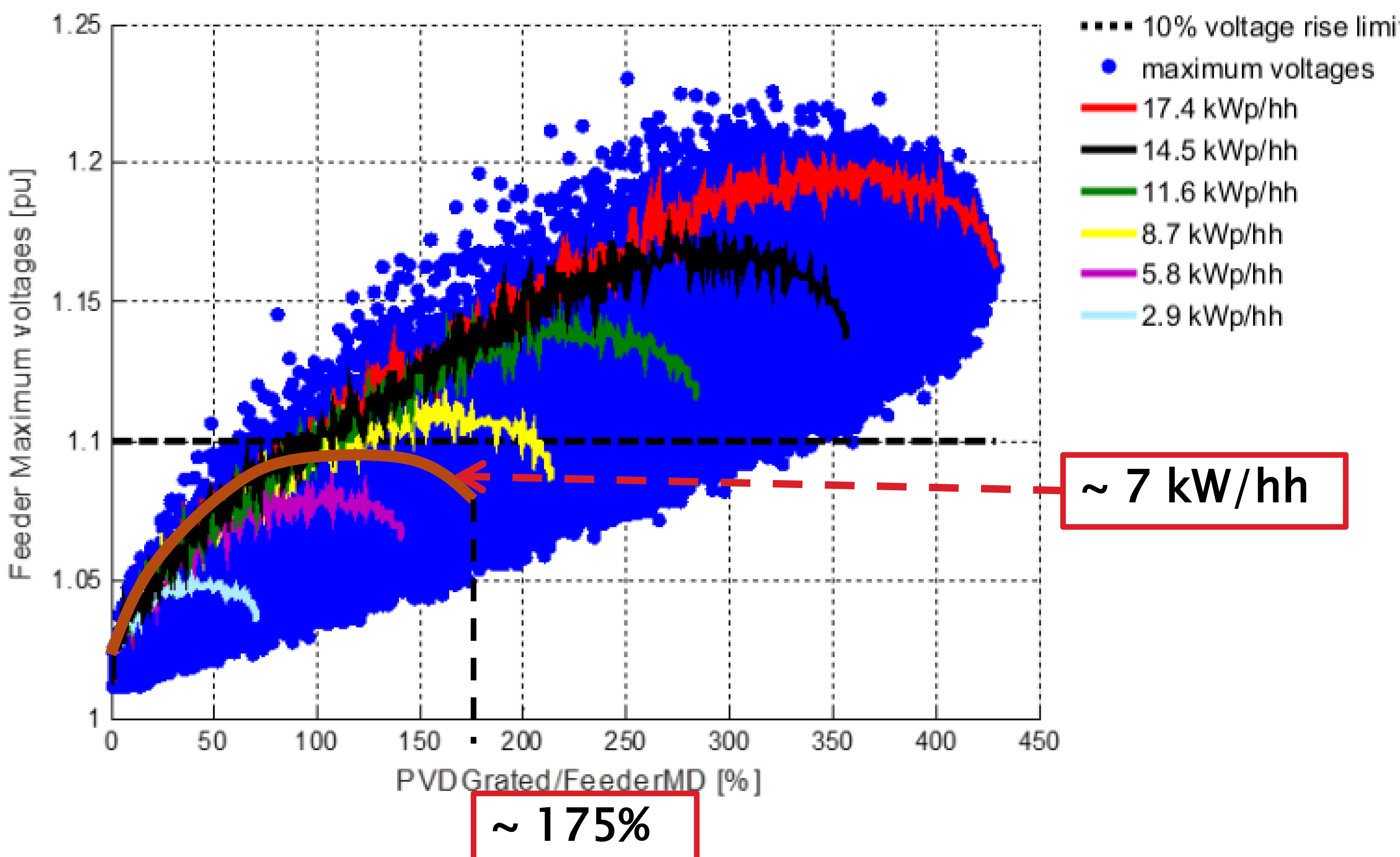
Current limit already exceeded in passive feeder

60%

PV penetration limit (with 5% risk of overload)

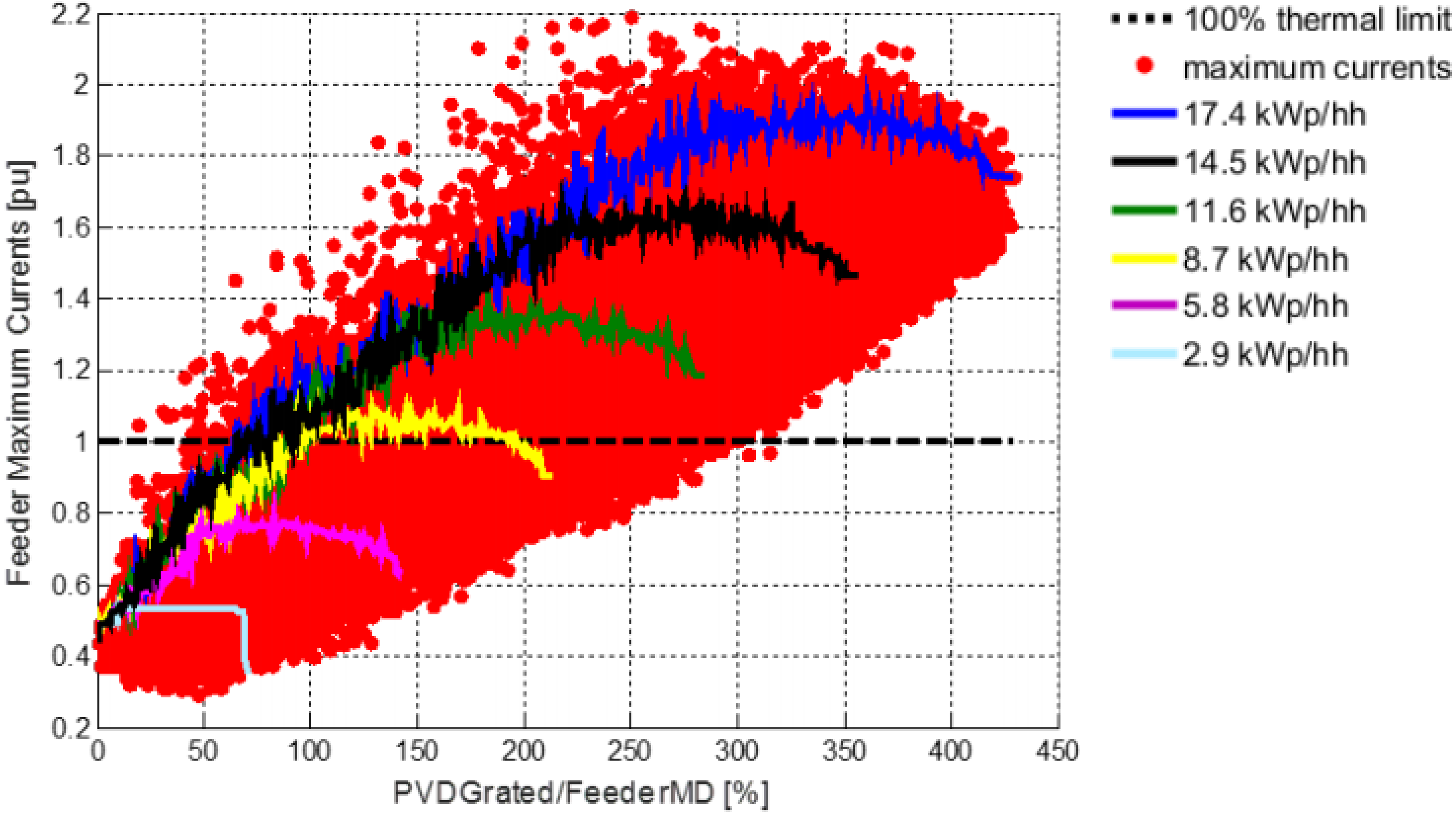
Some currents reduced by co-located DG and load, BUT others increase

Practical limits of installed capacity



Maximum voltages on the test feeder with increasing PVDG penetration

Practical limits of installed capacity



Maximum currents on the test feeder with increasing PVDG penetration

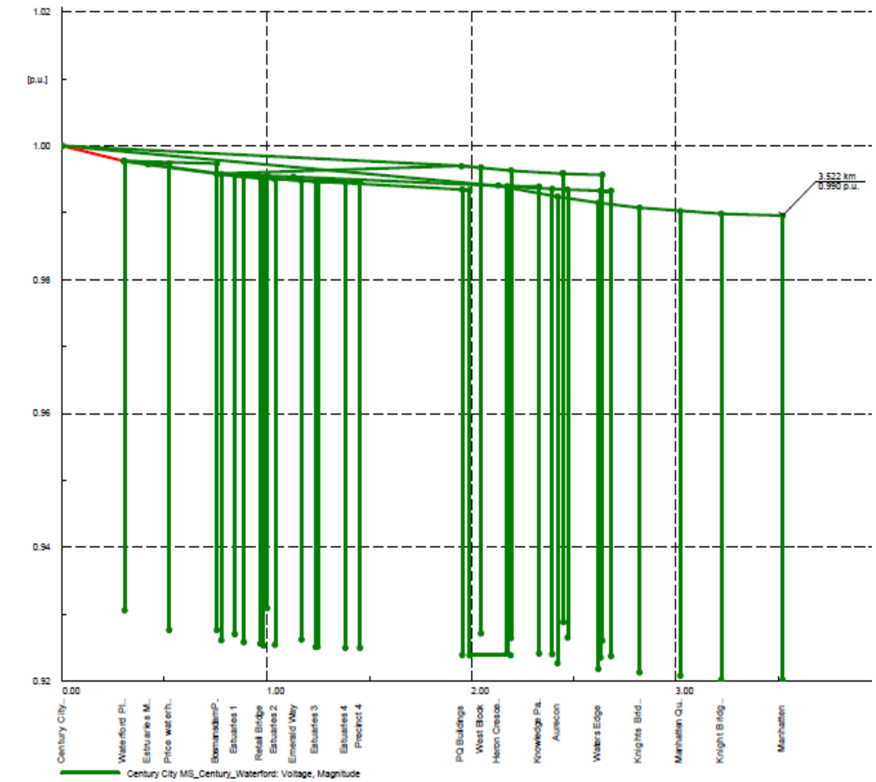
Findings

1) Roof space exceeds capacity of feeders to accommodate all rooftop PV DG. Limiting household injections (to about 7 kW/hh for SR feeder) increases overall hosting capacity.
2) Voltage rise limits on active feeders must consider correlated voltage rise on MV feeder:
   - 45~60% PV penetration if 7% LV voltage rise allowed
   - 10~20% PV penetration if only 4% LV rise allowed.
3) Some passive feeders already overloaded; not all DG alleviates overloading, depends on its location.
   - Thermal limits on PV DG depend on margin on passive feeder.
   - Every proposed installation would have to be studied before approval is granted

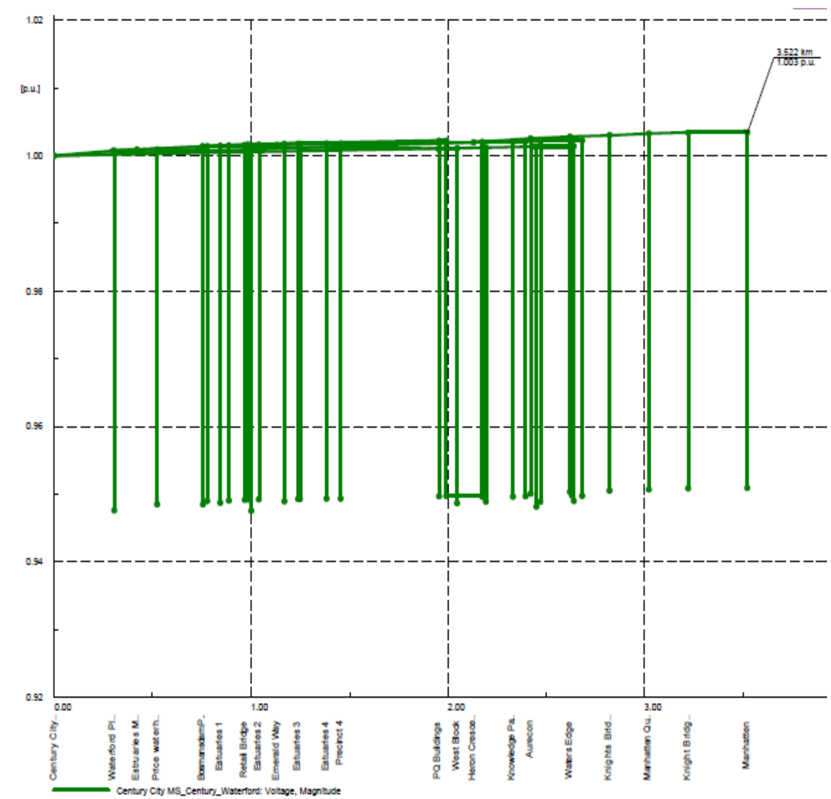
Caution

1) Results are based on a particular set of feeders and load models.
2) Penetration limits increase if maximum installed capacity of DG/hh is limited, and/or DG is restricted to 3-phase type.
3) Assumptions of correlated MV system variation are significant for capacity restricted by voltage rise.
4) Randomly located DG does not alleviate overloading.
5) Feeders with several long spurs require more detailed studies restricting the range of DG locations.

Voltage profiles



Passive system



Active system

Conformance to Practical models

- Storage not considered
  - Impacts the coincidence of high PV and low load
  - Has potential to reduce the impacts of high PVDG
- Inverter Active Voltage Control at PCC points not included
  - Enforces export limits (or disconnection) to ensure local bus bar voltage conditions are not violated
  - Has potential to reduce the extent of technical impacts

Recommendations

- Further studies investigating the impacts of storage on uptake limits
- Extension of the network models to include the mechanisms of modern inverter systems; e.g. voltage control through disconnection or reduction in export power