Cost-Benefit Assessment Challenges for a Smart Distribution System: A Case Study

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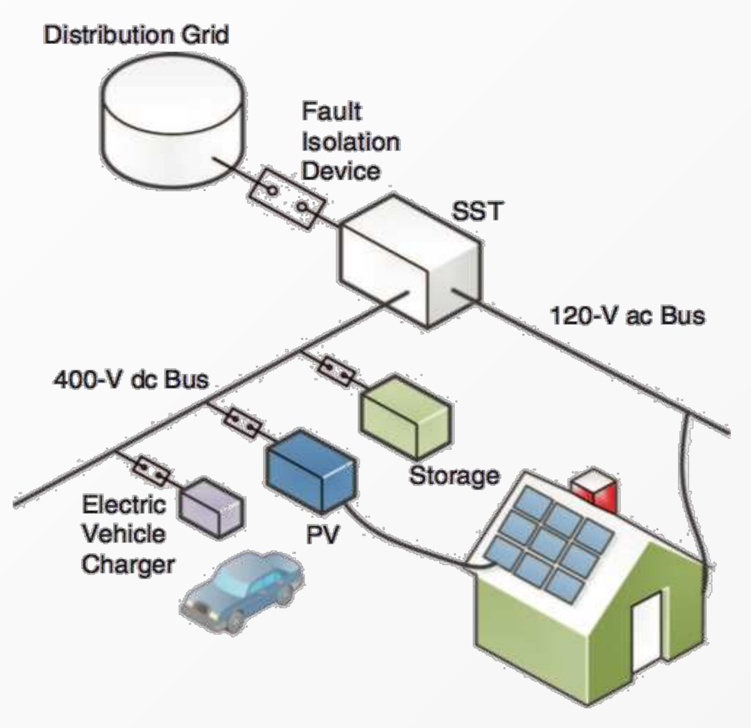
Background

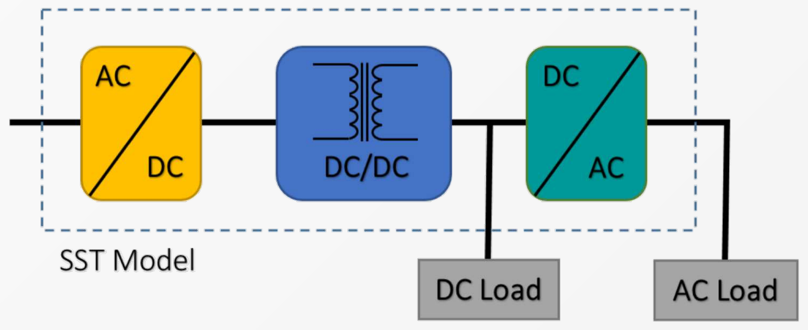
➢ FREEDM System Concept [1]

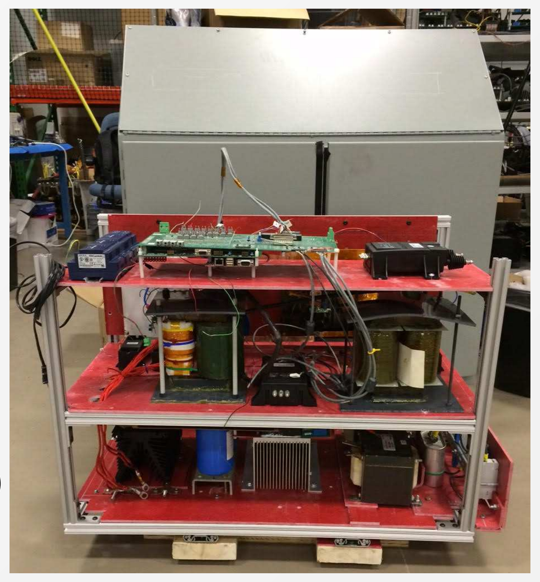


Use SST to replace traditional distribution transformer

- ❖ Control customer voltage
- ❖ Control power factor
- ❖ Provide DC service
- ❖ Energy management
- ❖ Real time monitoring
- ❖ Smaller and lighter

➢ Solid State Transformer (SST) [2]

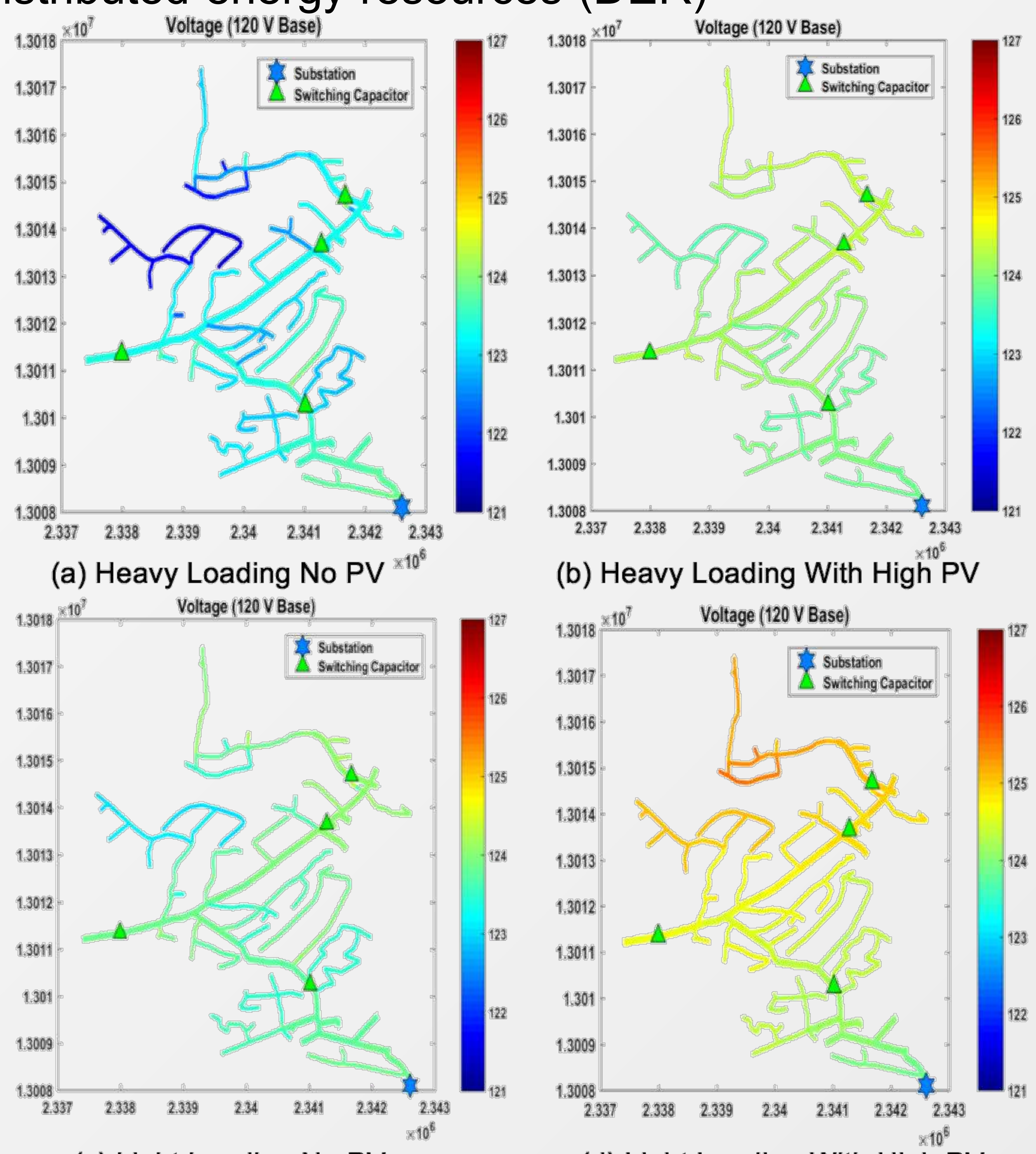




- ❖ Regulate voltage
  - Mitigating overvoltage caused by PV
  - Conservation voltage reduction (CVR)
- ❖ Reactive power compensation

Challenge

➢ Overvoltage issues caused by high penetration of distributed energy resources (DER)

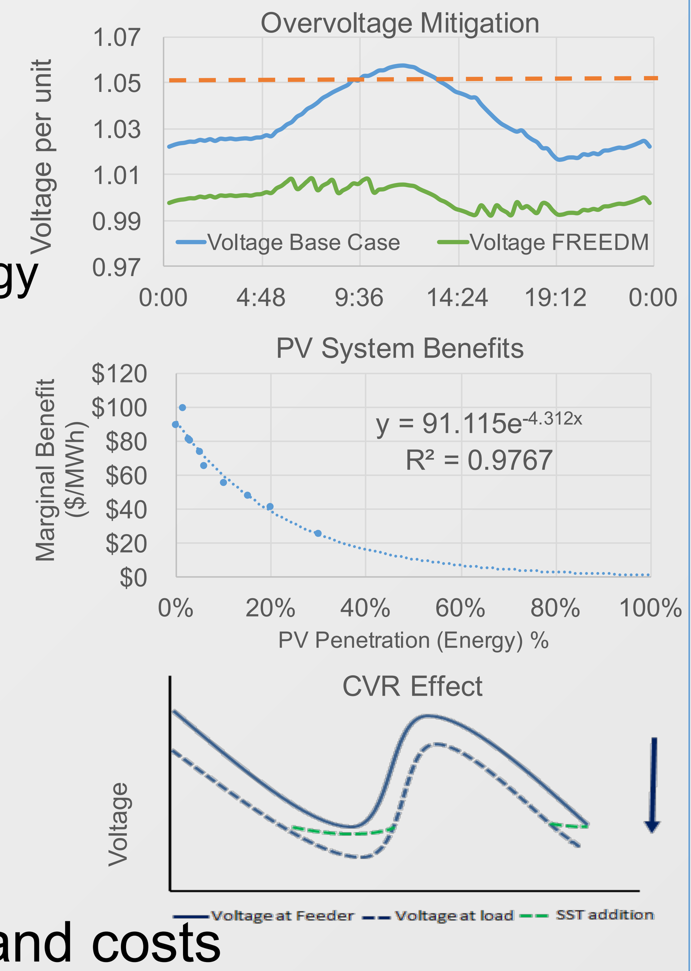


(a) Heavy Loading No PV
(b) Heavy Loading With High PV
(c) Light Loading No PV
(d) Light Loading With High PV

Cost Benefit Analysis Method

➢ Step 1: Identify the functions of the project that will provide new and/or additional benefits [3]

- Increasing PV hosting capacity
  - ✓ System benefits (Net benefits to utilities including avoided energy cost, deferred capacity expansion etc.)
- Conservation voltage reduction (CVR)
  - ✓ Avoided demand cost ($55/kW) [4]
  - ✓ Avoided energy cost ($0.05/kWh) [4]
- Control power factor
  - ✓ Reduce losses



➢ Step 2: Quantify benefits and costs

- Quasi-static time series simulation of utility feeders for 1-year time period using OpenDSS [5]
- SST cost used is $90-160/kVA for different sizes (Estimated based on prototype SST cost; larger production and product maturation considered)

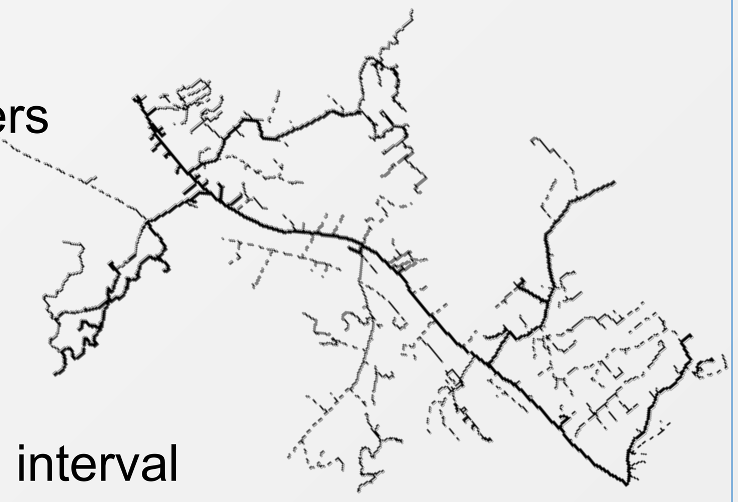
➢ Step 3: Perform a cost-benefit analysis

- Net present value (NPV) and Sensitivity analysis

Modelling

➢ Utility Circuit Model

- Three actual utility feeders
  - ✓ 12.47 kV, 3-5 Miles
  - ✓ 6-8 MW Peak
  - ✓ 300-500 Distribution Transformers
- Simulation run at 15 min interval



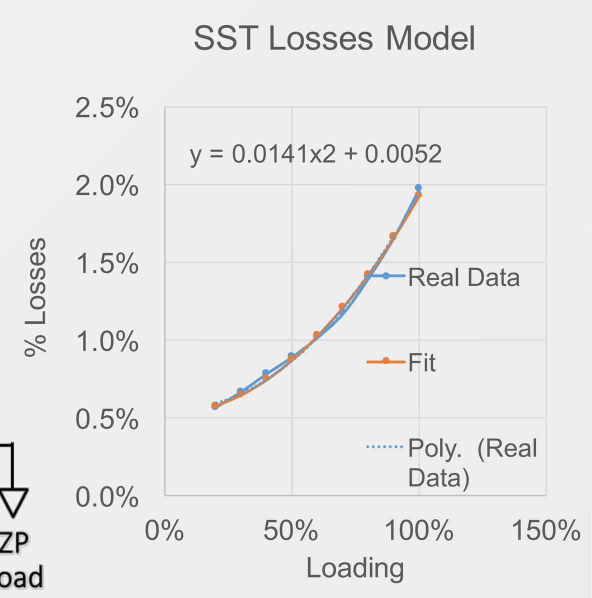
➢ FREEDM Partial Deployment Case Setup

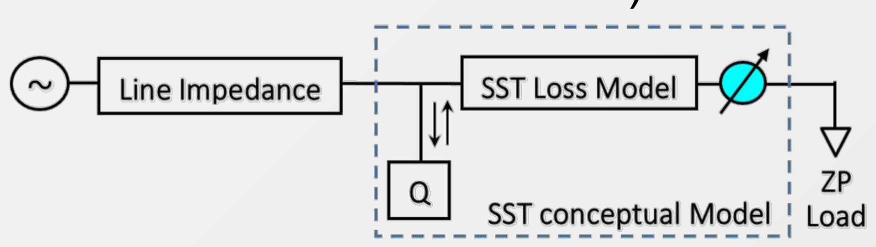
Cases	Description
(a) Base Case	Circuit + PV Cluster (Hosting Capacity)
(b) Higher PV	Circuit + PV Cluster (Higher Penetration) + FREEDM
(c) Higher PV plus CVR	Circuit + PV Cluster (Higher Penetration) + FREEDM +CVR

Note: CVR factor (delP/delV) simulated is 0.7

➢ SST Model In OpenDSS

- Using existing models
  - ✓ Set Q to 0
  - ✓ Voltage regulator
  - ✓ Transformer (Fitted Load Loss + No Load Loss)





Results

➢ Partial FREEDM Deployment Setup

Feeder #	PV Hosting Capacity	Higher PV Penetration	#SST Added	Overvoltage Elimination (% time/yr.)	CVR ΔV
A	32%	43%	36	2.70%	3.8V
B	46%	54%	16	0.4%	4.0V
C	33%	43%	58	1.32%	4.0V

➢ Partial FREEDM Deployment Results

Feeder #	Diff Δ	Energy MWh-yr.	Peak kW	Losses MWh-yr.		
				Circuit	XFMR	Total
A	PV	-1,227	4	-1	18	16
	CVR	-540	-169	1	-31	-31
	Total%	-2.3%	-2.4%	-0.002%	-0.06%	-0.1%
B	PV	-969	0	-4	0	-5
	CVR	-483	-92	0	-21	-20
	Total %	-1.4%	-1.2%	-0.01%	-0.06%	-0.1%
C	PV	-1,344	-16	-18	16	-2
	CVR	-559	-149	3	-36	-33
	Total %	-1.7%	-2.0%	-0.05%	-0.06%	-0.1%

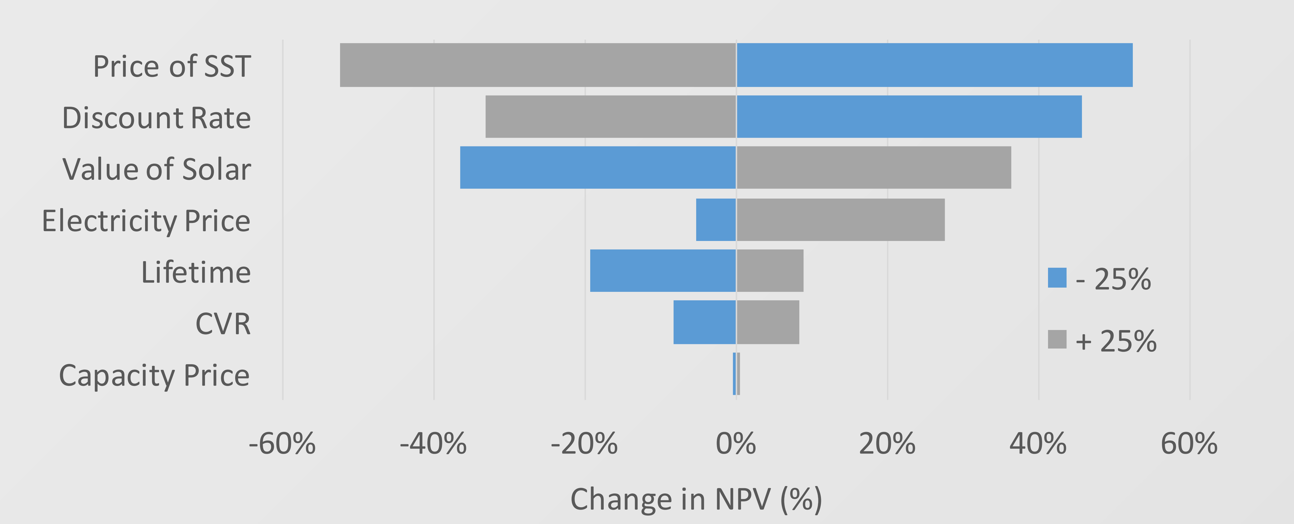
Note: "PV" results of case (b) Higher PV - (a) Base case
"CVR" results of case (c) Higher PV plus CVR - (b) Higher PV

➢ Cost benefits analysis results: NPV and Discounted Payback Period (DPBP)

#	Cost	DER Benefits (yr.)		Feeder Benefits (yr.)		NPV	DPBP (yrs.)
	SST	System	Avoided Demand	Avoided Energy	Avoided Demand		
A	$145k	$53k	$0	$27k	$9k	$669k	2.9
B	$41k	$42k	$0	$25k	$5k	$606k	1.6
C	$244k	$62k	$872	$29k	$8k	$657k	4

Sensitivity Analysis

➢ Parameters are varied by + 25% and - 25%



Conclusion

➢ FREEDM system increases DER hosting capacity.

➢ The cost-benefit analysis results presented a positive net present value for a partial deployment case with less than 5 years payback period for the sample feeders.

➢ The economic feasibility of the partial deployment scenarios considered indicates that early adoption of FREEDM systems is likely to be utilized on feeders with moderate DER penetration.

➢ The price of the SST and the discount rate are the most influential factors on the NPV.

[1] Alex Q. Huang, Medium-Voltage Solid-State Transformer, Technology for a Smarter and Resilient Grid, IEEE Industrial Electronics Magazine, 2016
[2] A. Huang, M. Crow, G. Heydt, J. Zheng and S.Dale, "The Future Renewable Electric Energy Delivery and Management (FREEDM) System: The Energy Internet", Proceedings of IEEE, vol. 99, no. 1, pp 133-148, 2011.
[3] Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects, EPRI (2010)
[4] Electric Energy Efficiency Potential for Pennsylvania, Final Report, Prepared for Pennsylvania Public Utility Commission, 2012.
[5] OpenDSS Program, EPRI Distribution System Simulator, [Online]. Available at SourceForge.net, https://sourceforge.net/projects/electricdss/