Techno-Economic Analysis for Grid Edge Intelligence: A Preliminary Study on Smart Voltage Regulator Controls

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BACKGROUND

Adverse impacts of variability in PV generation on the life/maintenance of tap changers can be reduced by adding intelligent autonomous controls for voltage regulators. Applications of a framework that can perform techno-economic analyses on smart voltage regulator control algorithms are presented in this work. The framework was developed at NREL and regulator control applications developed by Eaton Corporation were assessed with this framework to quantify performance improvements with grid edge intelligence.

TEST CASE

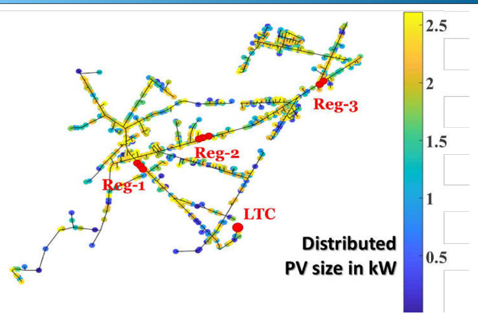


Figure: Topology of the test circuit (J1 feeder) with distributed PVs and locations of LTCs and line voltage regulators

ANALYSIS APPROACH

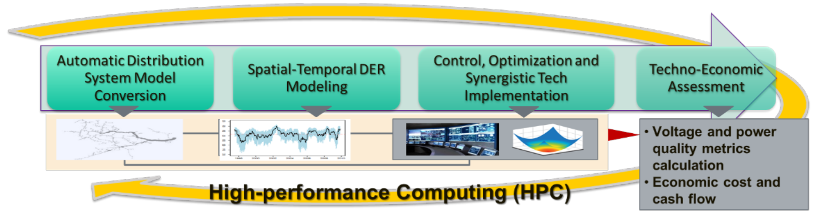


Figure: Capability description of SPEED-DER framework

- Leverages a Python-based techno-economic analysis tool (SPEED-DER) that uses OpenDSS as a power flow solver
- SPEED-DER can conduct quasi-static time-series simulations while integrating advanced control applications in a plug-and-play fashion
- Pluggable control applications, provided by Eaton, come as black box control modules
- Control application scenarios:
  - I. **Legacy control** with **default**, location-independent **delays**
  - II. **Legacy control**, with **modified** location-coordinated time **delays**
  - III. **Adaptive time delay control**
  - IV. **Adaptive voltage bandwidth control**

Optimizes the device performance by making the tap operations happen at the right time

EATON's controller modules

Analyzes recent voltage patterns statistically to select new regulator bandwidth settings

SIMULATION RESULTS

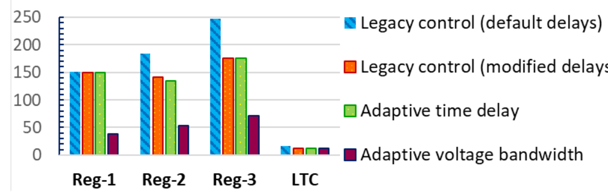


Figure: Tap change counts for voltage regulator clusters and LTC for selected 5-day simulation

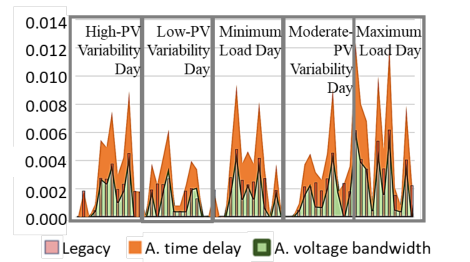


Figure: Long-term flicker severity indices results for selected 5-day simulation (< upper limit of 0.8)

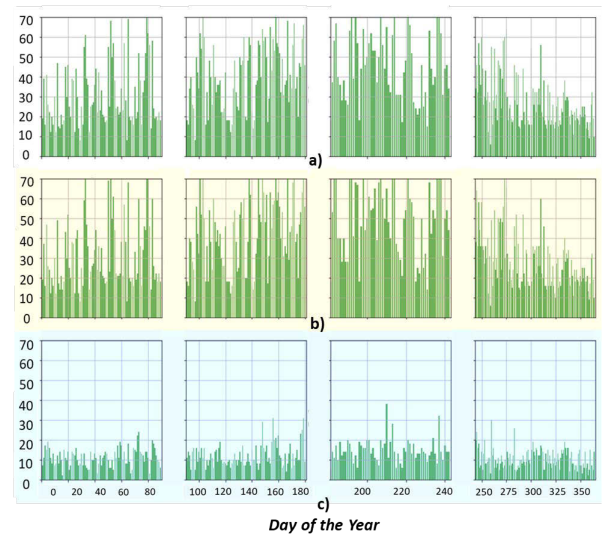
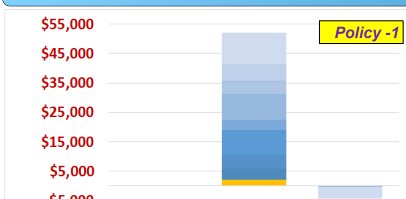
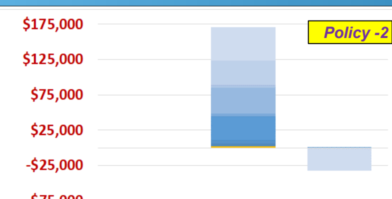


*Figure: Daily regulator tap change counts for Reg-3 with **a)** legacy control, **b)** adaptive time delay control, and **c)** adaptive voltage bandwidth control; from 1-year simulation*

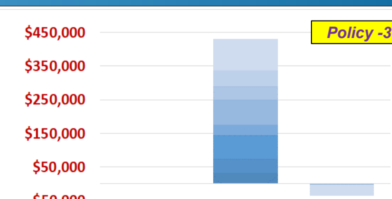
COST-BENEFIT ANALYSES



	Legacy	A. Voltage Bandwidth	A. Time Delay
Reg-3 (phB)	$0	$10,817	-$3,940
Reg-3 (phA)	$0	$5,527	$0
Reg-2 (phC)	$0	$4,661	-$68
Reg-2 (phB)	$0	$8,652	-$181
Reg-2 (phA)	$0	$3,694	$53
Reg-1 (phC)	$0	$8,254	$0
Reg-1 (phB)	$0	$4,729	$0
Reg-1 (phA)	$0	$3,641	$0
PV	$0	$0	$0
Losses	$0	$107	-$41
Load	$0	$2,108	$35



	Legacy	A. Voltage Bandwidth	A. Time Delay
Reg-3 (phB)	$0	$47,144	-$31,786
Reg-3 (phA)	$0	$34,320	$0
Reg-2 (phC)	$0	$4,661	-$68
Reg-2 (phB)	$0	$36,217	-$993
Reg-2 (phA)	$0	$3,694	$53
Reg-1 (phC)	$0	$33,887	$0
Reg-1 (phB)	$0	$4,729	$0
Reg-1 (phA)	$0	$3,641	$0
PV	$0	$0	$0
Losses	$0	$107	-$41
Load	$0	$2,108	$35



	Legacy	A. Voltage Bandwidth	A. Time Delay
Reg-3 (phB)	$0	$92,721	-$33,768
Reg-3 (phA)	$0	$47,375	$0
Reg-2 (phC)	$0	$39,947	-$585
Reg-2 (phB)	$0	$74,162	-$1,549
Reg-2 (phA)	$0	$31,662	$457
Reg-1 (phC)	$0	$70,745	$0
Reg-1 (phB)	$0	$40,532	$0
Reg-1 (phA)	$0	$31,205	$0
PV	$0	$0	$0
Losses	$0	$107	-$41
Load	$0	$2,108	$35

Figure: Differences in net present values for O&M costs between the legacy and other two control techniques for different maintenance policies

After a regulator has operated a predetermined number of times (100,000 for this study), a maintenance request can be issued.

Cost-benefit analyses are designed based on three maintenance policies for control devices:

- **Policy-1** : Replace its switching contacts
- **Policy-2** : Alternate replacing its contacts and replacing the entire device
- **Policy-3** : Replace the entire device

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