SAND2018-6097C

Algorithms to Effectively Quantize Scenarios for PV Impact Analysis using QSTS Simulation

Jeremiah Deboever[1], Santiago Grijalva[1], Matthew J. Reno[2], Robert J. Broderick[2]

[1] Georgia Institute of Technology, [2] Sandia National Laboratories

CONTEXT

- ✓ High penetration levels of PV systems on distribution networks can cause negative impacts on distribution systems (e.g. voltage extremes, excessive operation of voltage-regulating devices, etc.)
- ✓ Thus, interconnection studies are often recommended to fully understand the impact of a new installation.

QUASI-STATIC TIME-SERIES (QSTS) SIMULATION

- ✓ Simulates the temporal dimension of distribution system feeders.
- ✓ Considers the operation of voltage-regulating devices.

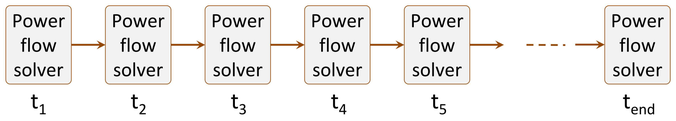
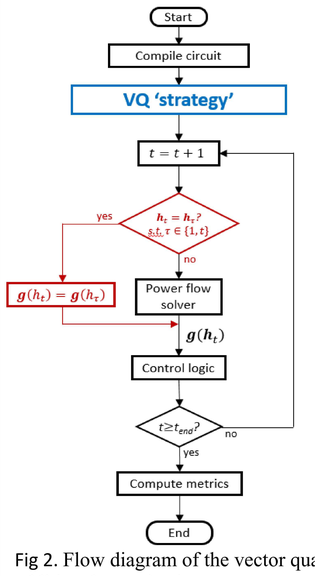


Fig 1. Illustrative diagram of a quasi-static time-series simulation.

- ✓ Time horizon & time-step resolution:
  - Suggested time horizon is 1 year.
  - Suggested resolution below 5 seconds.

VECTOR QUANTIZATION ALGORITHM

- ✓ Computational time to solve a yearlong QSTS simulation at 1 second resolution (31.5 million power flows) is a burden.
- ✓ By leveraging similarities in power flow solutions, the VQ algorithm can reduce simulation time.



Unique power flow solutions can be defined by:
- Load conditions
- PV output power
- Regulator states
- Capacitor states

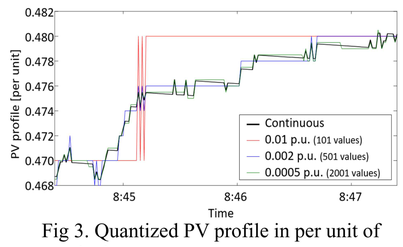


Fig 3. Quantized PV profile in per unit of nominal power output.

Fig 2. Flow diagram of the vector quantization algorithm discussed in [1] with the additional quantization strategy proposed in this work.

- ✓ Arbitrary vector quantization can yield to suboptimal results.

TABLE 1. Simulation results presented in [1] where the number of discrete values in each profile is varied.

# of values (Load, PV)	Error in the reported # of Tap change [%] Reg1 / Reg2 / Reg3	% reduction in comp. time
Brute Force	**7014 / 7202 / 8411**	-
101, 51	0.2% / -0.2% / -0.1%	99.44 %
51, 101	-1.4% / -4.2% / 1.0%	99.43 %
51, 51	-1.9% / -4.8% / 0.3%	99.49 %

SENSITIVITY-BASED VECTOR QUANTIZATION

❑ **Proposed vector quantization algorithm:**

- ✓ Each time-series profiles affect the various controllers differently.
- ✓ A perturb-and-observe sensitivity analysis determines how each controller is affected by a power injection (load or PV)
- ✓ The profiles are quantized according to ratio of the maximum disturbance they created (e.g. 565/113 = 5:1 ratio).

❑ **Sensitivity analysis results:**

TABLE 2. Sensitivity analysis of the impact of each profile (1p.u. variation) on the different controllers in the modified IEEE 13 bus test case as a percentage of the deadband.

	Reg1	Reg2	Reg3	CAP1
Deadband	1.5 V	1.5 V	1.5 V	3.0 V
Load	-438 %	-438 %	-565 %	-352 %
PV	80 %	82 %	83 %	113 %

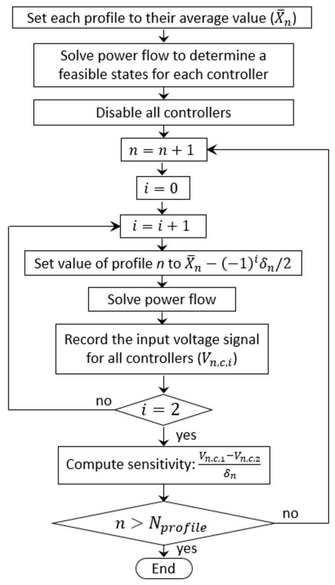


Fig 4. Flow chart of the sensitivity analysis algorithm conducted for the proposed VQ strategy.

SIMULATION RESULTS

- ✓ 576 QSTS simulations were conducted where the quantization for each profile is varied to record their speed and accuracy.
- ✓ Three traces compare three different vector quantization strategies: a uniform VQ (1:1), a kVA-based VQ (5:2), and the proposed VQ (5:1).
- ✓ Note that simulation A, B, & C have similar computational speed but different reported accuracies.

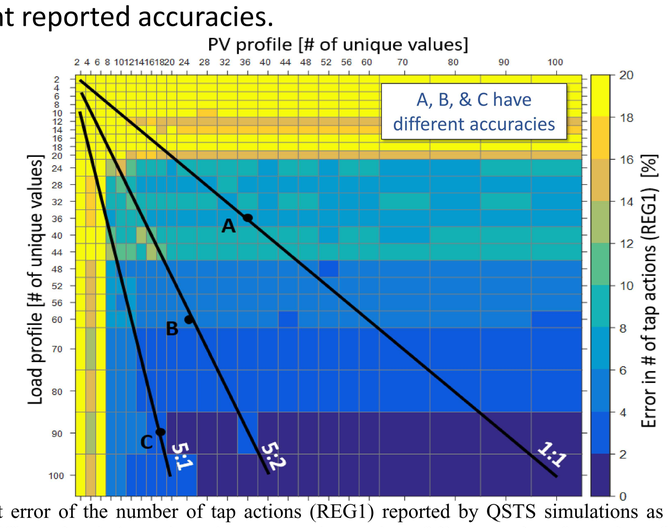


Fig 5. Percent error of the number of tap actions (REG1) reported by QSTS simulations as the profiles are quantized at different levels (x- and y-axis represent the number of discrete values for each profile).

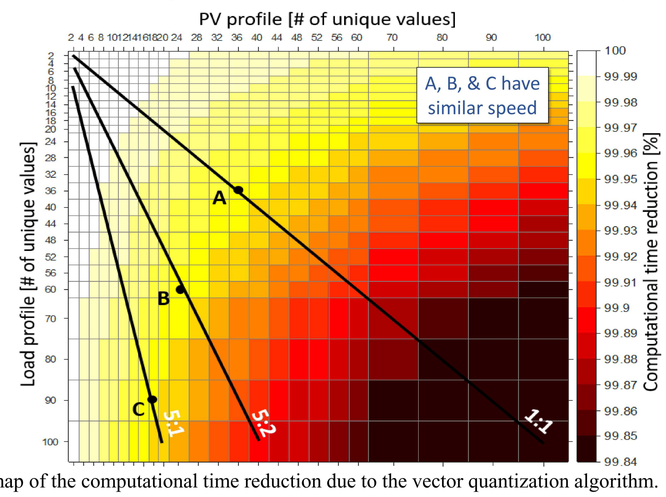


Fig 6. Heat map of the computational time reduction due to the vector quantization algorithm.

VALUE OF PROPOSED ALGORITHM

- ✓ The behavior in Fig. 5 can be predicted from the voltage sensitivity analysis without running all 576 QSTS simulations.

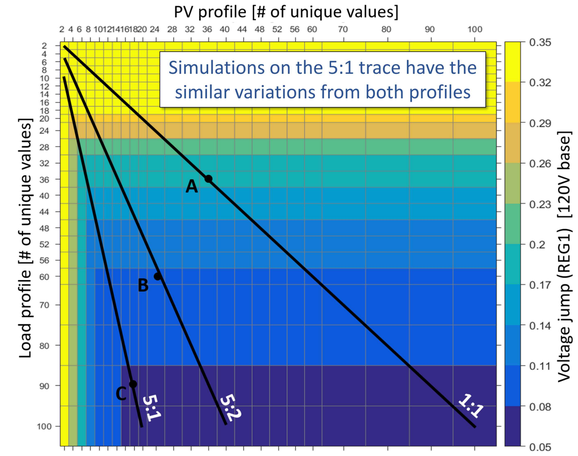


Fig 7. Maximum voltage variation created by the change from one discrete value to another in either profiles (load or PV), whichever is larger.

DISCUSSION

- ✓ Relocating the PV system to other buses can alter how a device is affected by it.

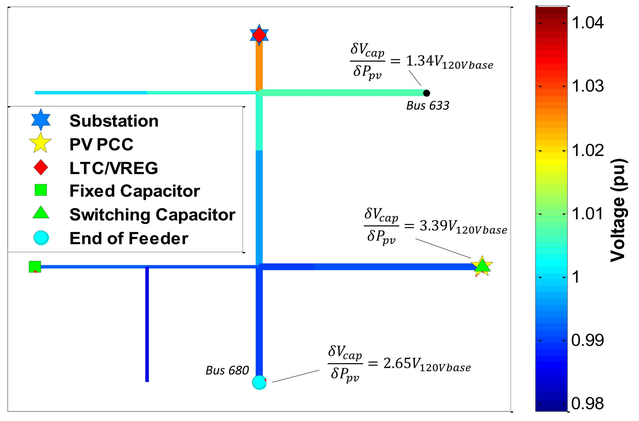


Fig 8. Variation in the voltage input signal of the switching capacitor created by the PV system if it were moved to three different locations.

CONCLUSION

- ✓ An efficient methodology to quantize the load and PV profiles is proposed to balance computational speed and accuracy.
- ✓ It quantizes profiles based on their impacts on voltage-regulating devices.
- ✓ The perturb-and-observe sensitivity analysis makes it circuit-specific and does not require prior knowledge.

ACKNOWLEDGEMENT

This research was supported by the DOE SunShot Initiative, under agreement 30691. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

CONTACT

Jeremiah Deboever, PhD
Phone: 404-894-2901, Email: jeremiah.deboever@gmail.com