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Scalability of the Vector Quantization Approach for Fast QSTS Simulation

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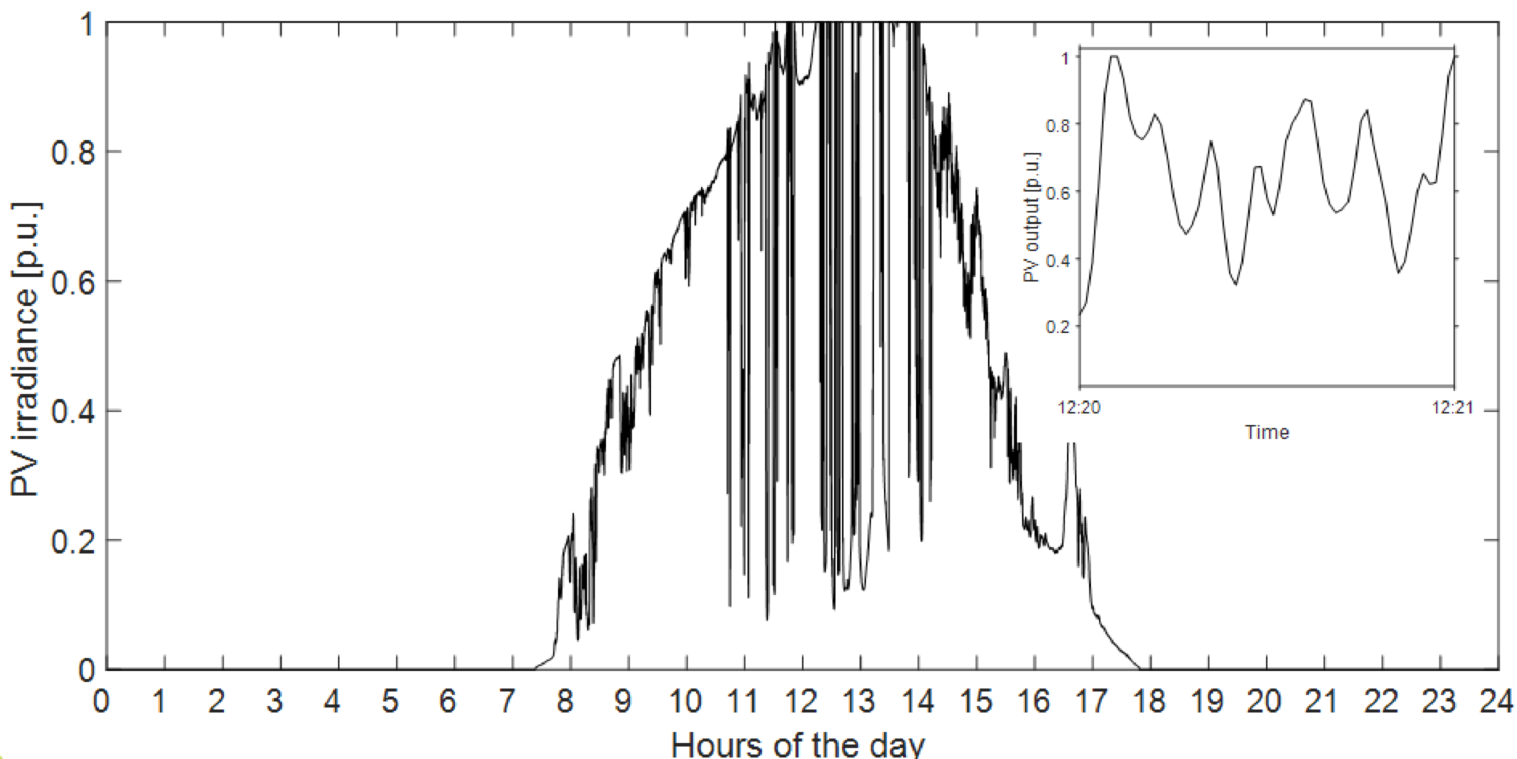
Outline

- Brute force Quasi-Static Time-Series (QSTS) simulation
- Current vector quantization algorithm
- Scalability of the algorithm
- Simulation results
- Contributions and broader picture

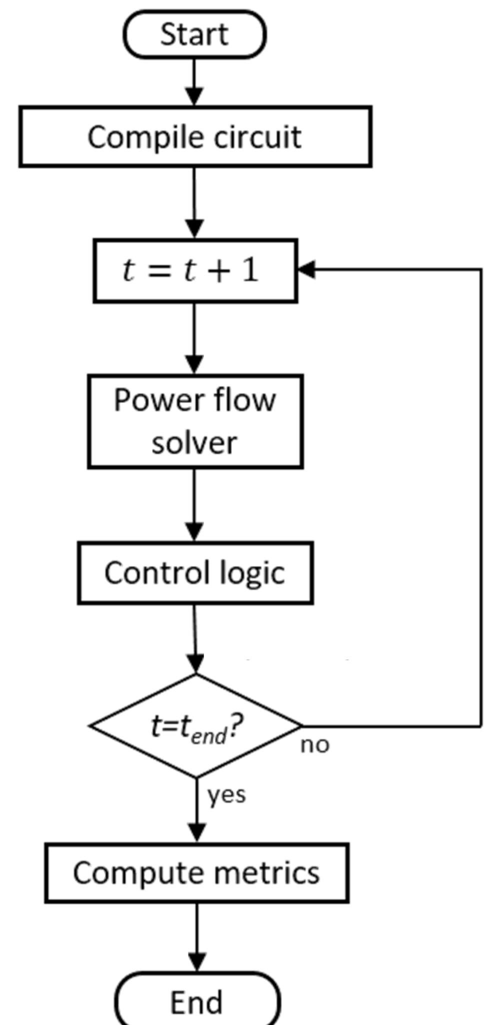
Detailed PV interconnection studies

- PV system can create disturbances in the operation of distribution systems



Brute force approach to QSTS simulations

- At each time-step, the simulation goes through:
  - AC, unbalanced, three-phase iterative power flow solver
  - Control logic of any controllers
- Solves each time step chronologically to capture the controller states with hysteresis
- A yearlong simulation at 1-second resolution can take 10-120 hours

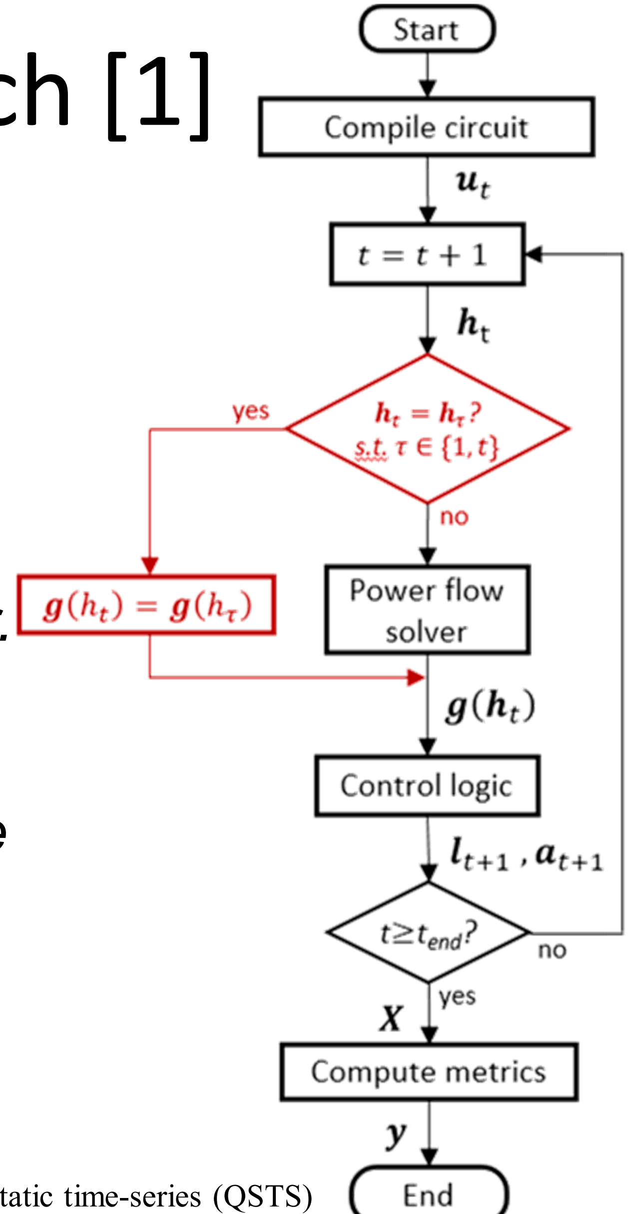


Vector Quantization Approach [1]

Objective:
To bypass the slow iterative power flow solver

Concept:
Take advantage of very similar power flow computations to alleviate the solver altogether.

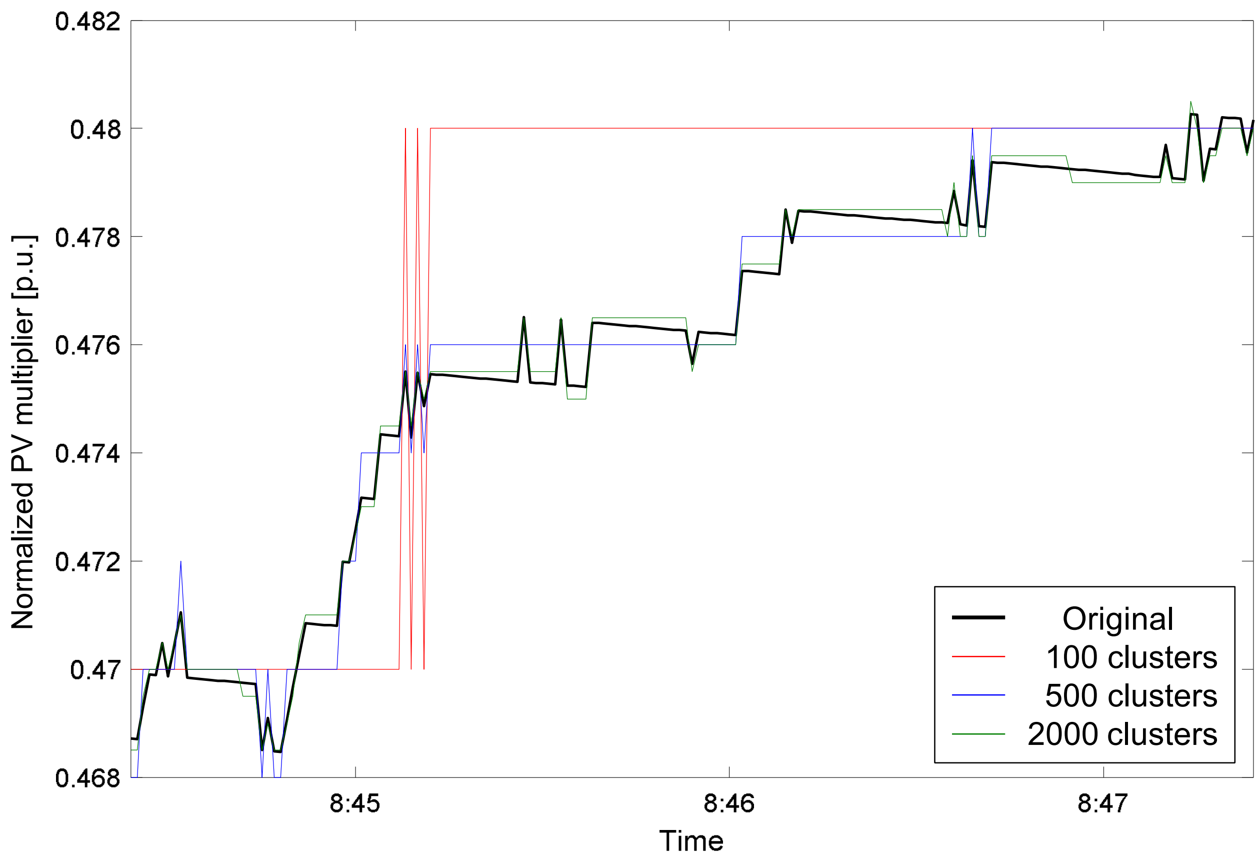
Execution:
Identify a vector of factors that define a unique power flow solution.
i.e. $\boldsymbol{h}_t = [load_t, PV_t, Reg, Cap]$



[1] **J. Deboever**, S. Grijalva, M. J. Reno, and R. J. Broderick, "Fast quasi-static time-series (QSTS) for yearlong PV impact studies using vector quantization," *Sol. Energy*, p. Under Revision.

Vector Quantization Approach

- Vector quantization of vector $\boldsymbol{h}_t$ reduces the number of unique power flows



Vector Quantization Approach

- Simulation results in [1]:
  - ~96% reduction in computational time
  - Modified IEEE 13-bus test circuit
    - 3 controllable regulators, 1 controllable capacitor bank
    - 1 load profile
    - 1 PV profile
- Scalability issues:
  1. Size of the feeder (number of buses)
  2. Number of load/PV profile
  3. Number of controllable elements
  4. Type of controllers

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1. Size of the distribution feeder

- Addressed for feeders with 1000’s of buses

2. Number of Load/PV profile

- Capable of modeling multiple load profile and multiple PV profiles

3. Number of controllable elements

- Capable of simulating feeders with multiple regulators and capacitor banks

4. Types of controllers

A. Dependent on time

i.e. power output of the PV system

- - > treated as a profile

B. Dependent of power flow solution **with** hysteresis

i.e. voltage regulating tap changer (with delays)

- - > treated a state defining the power flow solution

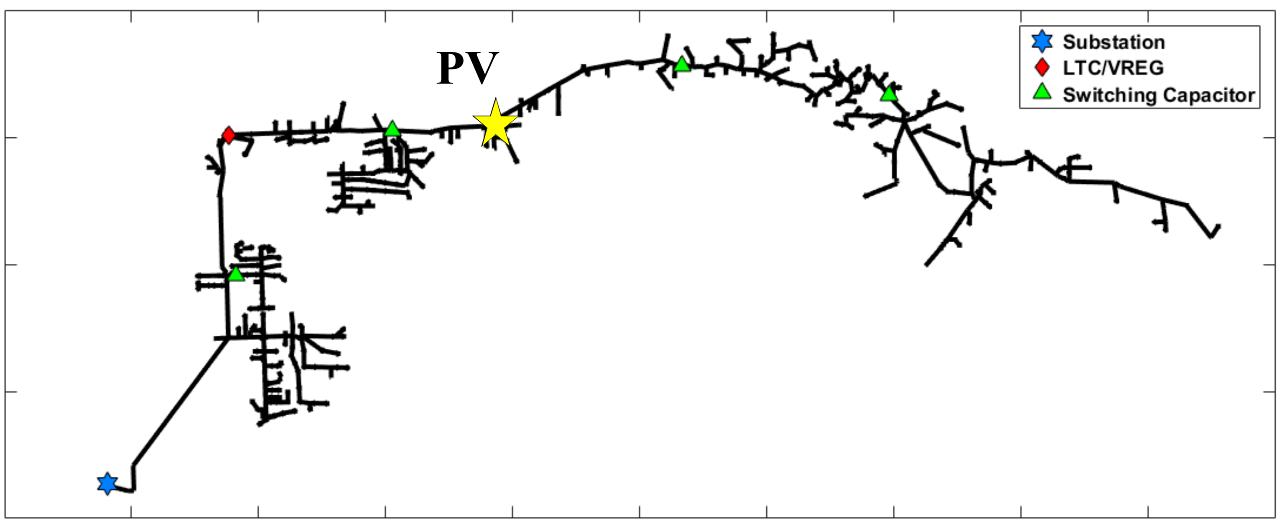
C. Dependent of power flow solution **without** hysteresis

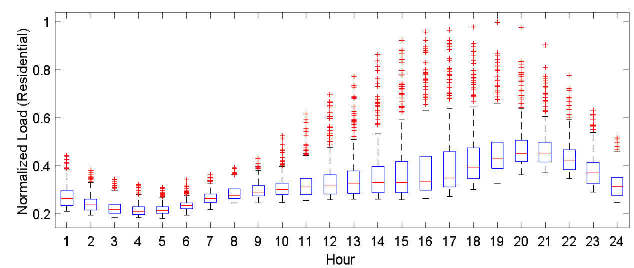
i.e. volt/var controller

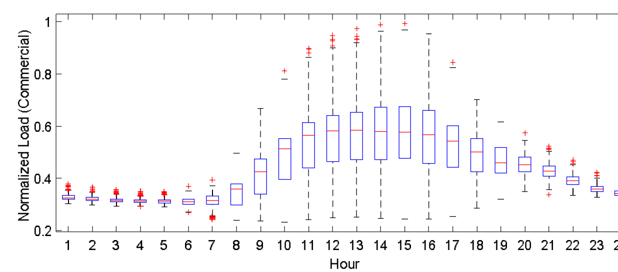
- - > included within the power flow solver

Simulation

- Realistic distribution system feeder:
  - 2969 buses
  - 3 profiles: (2) load profile, (1) PV profile
  - 8 controllers: (1) 3-θ LTC, (3) 1-θ LTC, (4) cap. Bank







Simulation Results

- Modeled in OpenDSS through a MATLAB interface
- Window 10 computer with 32GB of memory and a 3.50GHz processor
- Solved in 28 minutes instead of 36.1 hours

Profile (All)	LTC (Sub)		Regulator REG1		REG2		REG3		Comp. Time [sec]	
BruteForce	2702	-	9031	-	12656	-	10782	-	36.14	100.0%
VQ (200)	2716	0.5%	9237	2.3%	12974	2.5%	11038	2.4%	2.62*	7.2%
VQ (100)	2746	1.6%	9677	7.2%	13344	5.4%	11376	5.5%	1.17*	3.2%
VQ (50)	2778	2.8%	9517	5.4%	13305	5.1%	11324	5.0%	0.47*	1.3%

* Comp. times include the slow MATLAB interface

Contribution and broader picture

- Improved the vector quantization algorithm of [1] to simulate distribution system feeders of any complexity.
- Capable of 93-99% computational time reduction with minimal accuracy error

- > Provides system planners the capability for time series impact analysis for new PV interconnections

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Questions?

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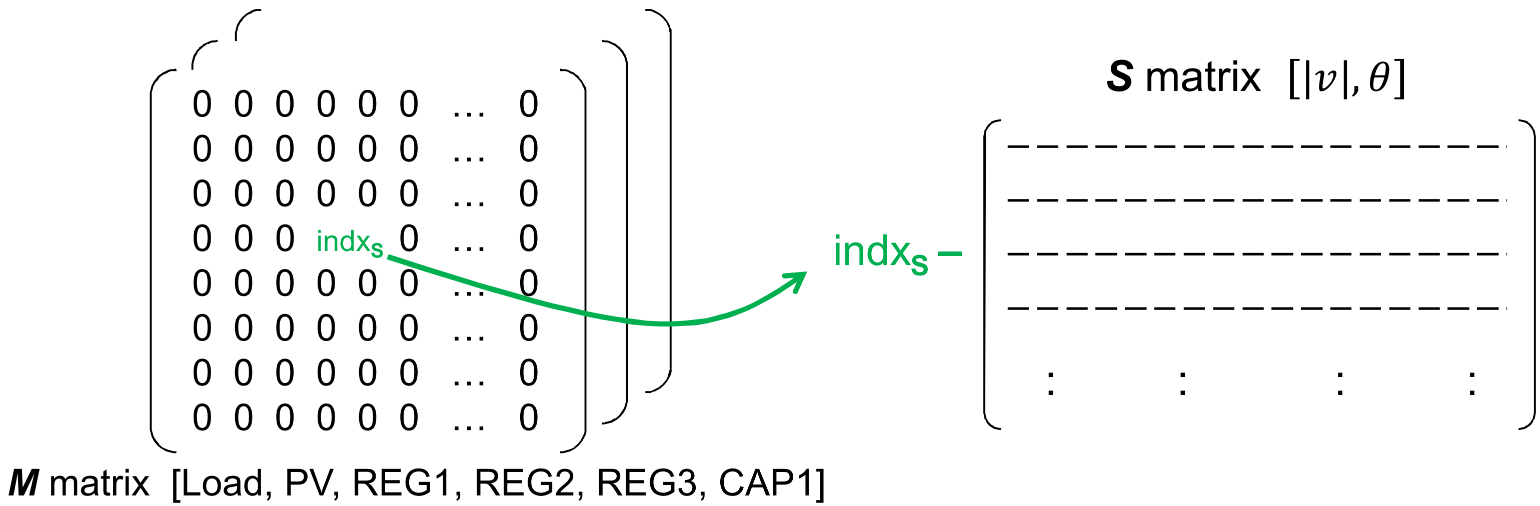
Vector Quantization Approach

- <u>Matrix indexing</u>:



- <u>Scalability issues</u>:
  1. Size of the feeder (number of buses)
  2. Number of load/PV profile
  3. Number of controllable elements
  4. Type of controllers

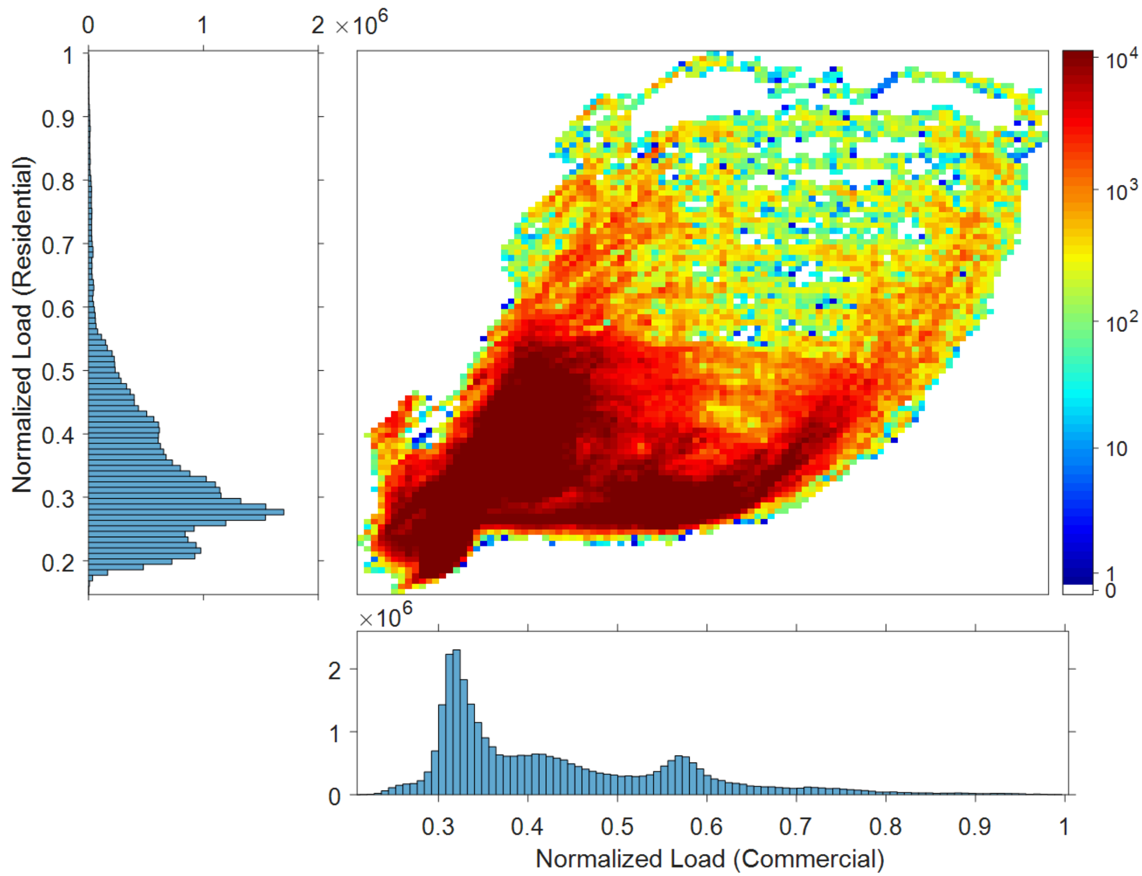
1. Size of the distribution feeder

- The logic behind the algorithm is independent of the number of buses in the model
- But the computational time is slightly impacted by larger circuit because some power flows are still solved:

$$T_{comp.} = \left(\frac{T_{brute\ force}}{31.5e^6}\right) N_{pf\ solved} + T_{CL} + T_{VQ}$$

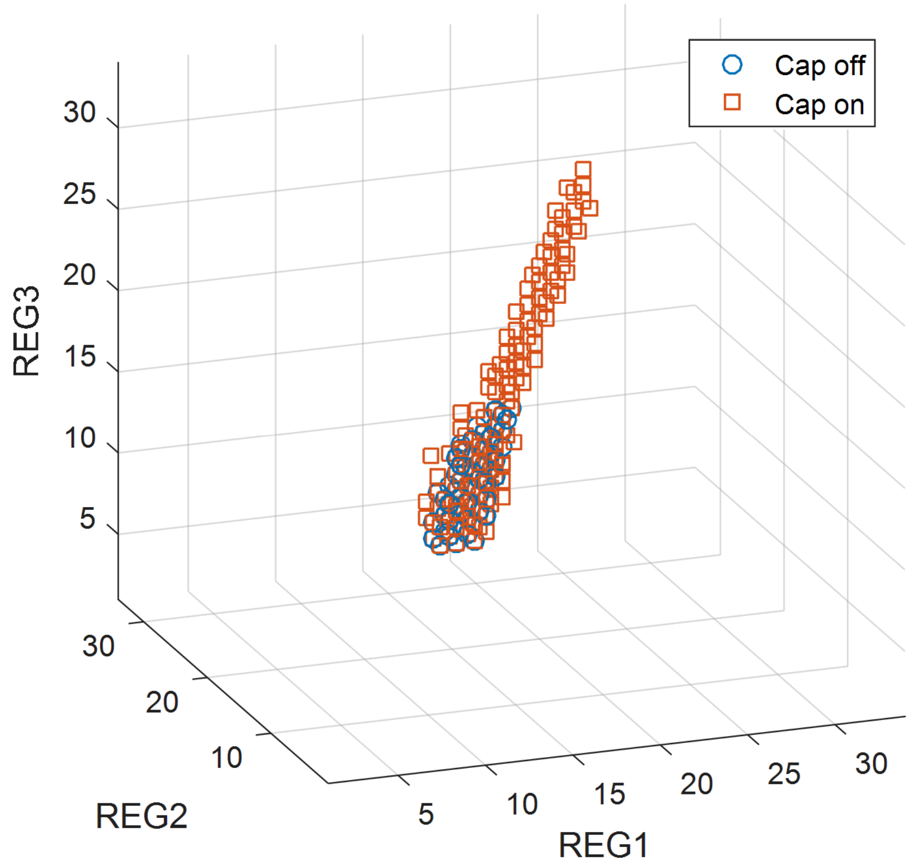
2. Number of load/PV profile

- There are similarities between profiles and not all scenarios are experienced.



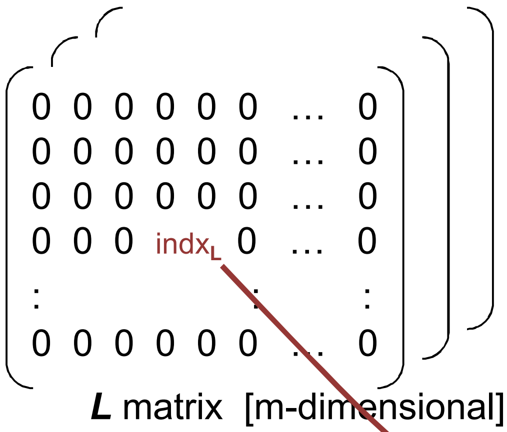
3. Number of controllable element

- There are similarities between controller states and not all combinations are experienced.

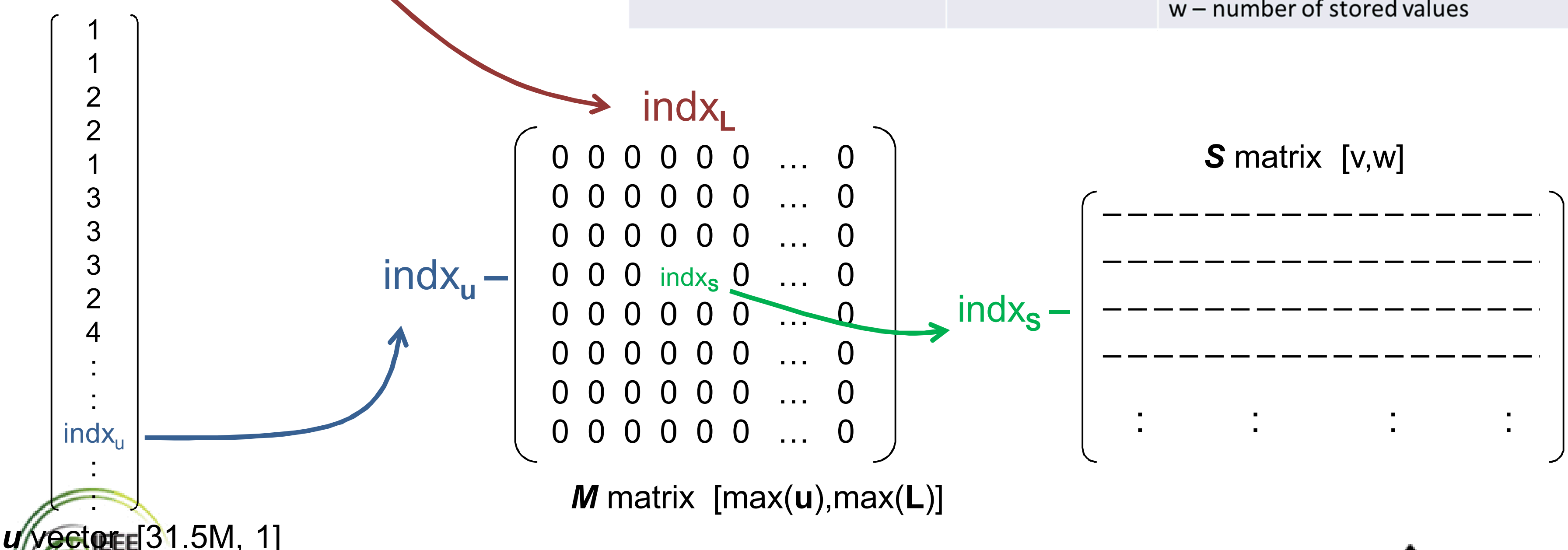


*Tap position

Proposed scalable algorithm



Matrix	Size	Description
$\boldsymbol{U} = [\boldsymbol{d}(t), \boldsymbol{p}_{pv}(t)]$	31.5M-by-n	Matrix with n profile
$\boldsymbol{u} = \text{unique}(\text{U}, \text{row})$	31.5M-by-1	Time-series vector
$indx_{\boldsymbol{u}} = \boldsymbol{u}(t)$	Value	Index value for M-matrix
$\boldsymbol{L} = zeros(33,33,33,2)$	m-dimensional	Matrix with m controllable elements
$\boldsymbol{l} = [\text{reg1}, \text{reg2}, \text{reg3}, \text{cap1}]$	1-by-m	Controllable element states
$indx_{\boldsymbol{L}} = \boldsymbol{L}([\boldsymbol{l}(t)])$	Value	Index value for M-matrix
$\boldsymbol{M}(indx_u, indx_l)$	Max(**u**)-by-max(**L**)	Indexing matrix
$\boldsymbol{S}(indx_{\boldsymbol{S}}, :)$	v-by-w	Solution matrix (v – number of unique sol, w – number of stored values



Brute force approach to QSTS simulations

- Input vector: $\boldsymbol{u}_t := [\boldsymbol{d}_t, \boldsymbol{p}_{pv,t}]$
- Power flow input vector: $\boldsymbol{h}_t := [\boldsymbol{u}_t, \boldsymbol{l}_t]$
- Power flow output vector: $\boldsymbol{g}_t := [|\boldsymbol{v}_t|, \boldsymbol{\theta}_t]$
- Control logic states:
  - Controller states: $\boldsymbol{l}_t := [\boldsymbol{r}_t, \boldsymbol{c}_t]$
  - Delay accumulators: $\boldsymbol{a}_t := [\boldsymbol{a}_{r,t}, \boldsymbol{a}_{c,t}]$
- System states: $\boldsymbol{x}_t := [\boldsymbol{h}_t, \boldsymbol{g}_t]$