VIRGINIA TECH

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PEC
Power and Energy Center

Volt/Var Optimization by Smart Inverters and Capacitor Banks

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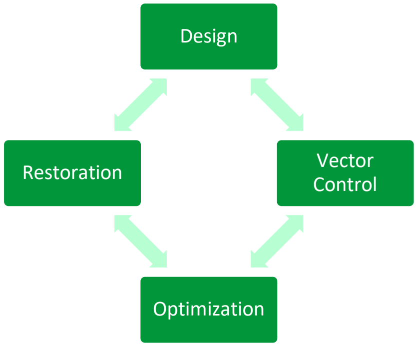
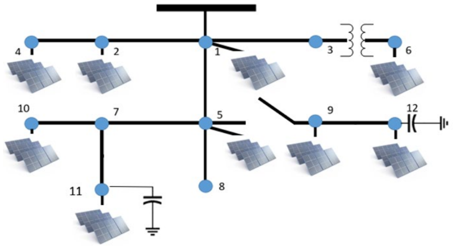
Overview

- Change within the electric power system (EPS) is due to an increased penetration of distributed energy resources (DERs)
- Electric power system should have a *secure* and *resilient operation*



Volt/Var Optimization



Motivation

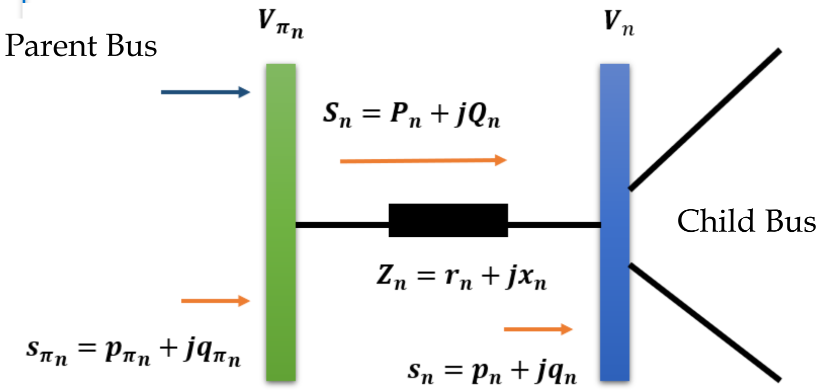
Challenge

- Diverse loads have been added to the EPS and load forecast have been difficult to predict
- Secure voltage performance of distribution systems

Solution

- Control inverters for Volt/VAR control (VVC) can provide a faster response for voltage regulation
- Switched capacitor banks and inverters can work together to mitigate the voltage deviation
- Traditional devices are transformer load tap changers and voltage regulators

Prior Work



Linearized distribution flow (LinDistFlow)

$$v_n \approx v_{\pi_n} - 2r_nP_n - 2x_nQ_n$$

$$s = A^T S$$
$$X = 2A^{-1}diag(x)A^{-T}$$
$$R = 2A^{-1}diag(r)A^{-T}$$

$$\Delta v \simeq Rp + Xq$$

$$P_n = \sum_{k\in C_n} P_k - p_n \qquad Q_n = \sum_{k\in C_n} Q_k - q_n - b_n^{sh}v_n$$
$$s = p + j(q + q^s)$$
$$v = J(Rp + Xq + 1_N v_o)$$

- Based on a radial Network
- R & X are positive definite matrix

V. Kekatos, L. Zhang, G. B. Giannakis, and R. Baldick, "Fast localized voltage regulation in single-phase distribution grids," 2015 IEEE International Conference on Smart Grid Communications (SmartGridComm), Miami, FL, 2015, pp. 725-730.

Problem Statement

Linearized Distribution Flow (LDF) model with Capacitor Banks

$$\boldsymbol{\Delta V} = \boldsymbol{R}\,(\boldsymbol{p_g} - \boldsymbol{p_c}) + \boldsymbol{X}((\boldsymbol{q_g} - \boldsymbol{q_c}) + \boldsymbol{q_{cb}})$$

Measured Values

Unknown Variable

Unknown Binary Variable

$$\min \quad \|\Delta V\|_2^2$$

s.t.

$$v = R(p_g - p_c) + X(q_g - q_c) + q_{cb} + v_0 1$$
$$p_g^2 + q_g^2 \leq (s_g^{max})^2$$
$$\Delta V = v - v_0 1$$
$$(0.97)^2 \leq \Delta V \leq (1.03)^2$$
$$-x_s M \leq q_{cb} \leq x_s M$$
$$-M(1 - x_s) \leq q_{cb} - v_c \omega C \leq (1 - x_s) M$$
$$x_s \in \{0,1\}$$

$$q_{cb} = x_s v_c \omega C$$

$$q_{cb} = \begin{cases} v_c \omega C, & x_s = 1 \\ 0, & x_s = 0 \end{cases}$$

Optimization variables are:

q_{cb} = Capacitor banks reactive power

q_g = Reactive power generative from the PV and Battery Storage

Where the measured values are:

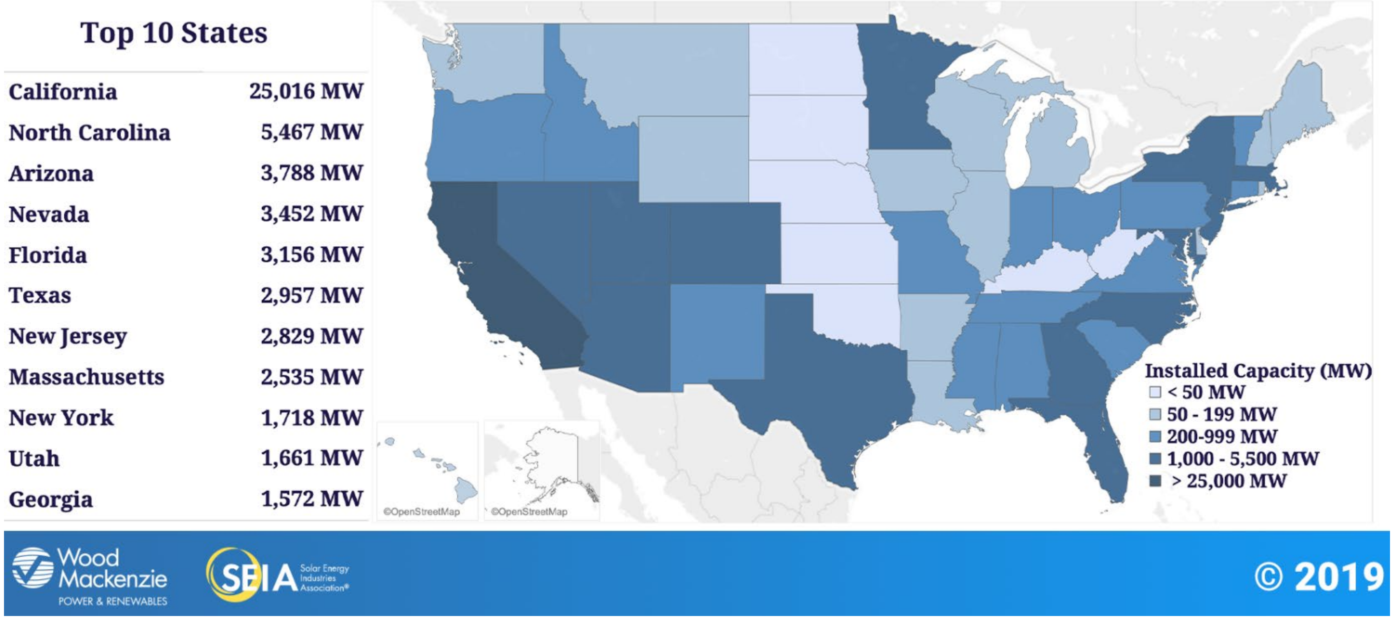
p_g = Active solar and battery generation

p_c =Active load consumed

q_c =Reactive load consumed

- The apparent power capacity of the inverter is considered.
- The Big M method is used to linearize the product of the two variables.
- This is a Mixed-Integer Quadratic Programming (MIQP) problem.

PV Generation

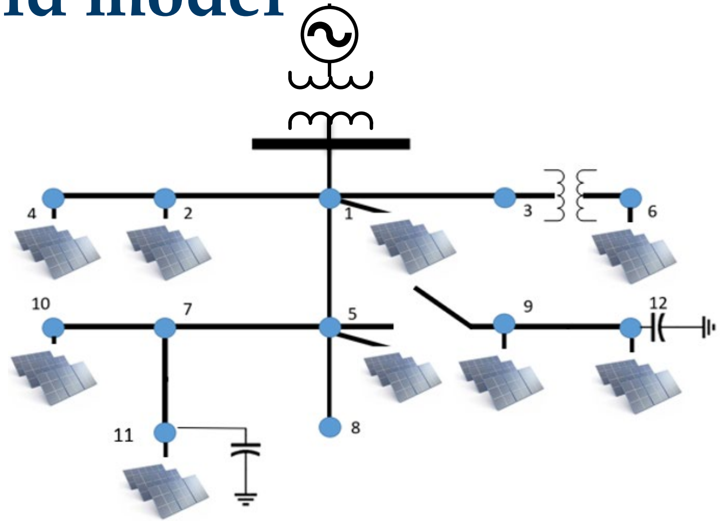


Top 10 States

California	25,016 MW
North Carolina	5,467 MW
Arizona	3,788 MW
Nevada	3,452 MW
Florida	3,156 MW
Texas	2,957 MW
New Jersey	2,829 MW
Massachusetts	2,535 MW
New York	1,718 MW
Utah	1,661 MW
Georgia	1,572 MW

6 https://www.seia.org/sites/default/files/inline-images/SIDP-2019Q2-Fig7-Map.png

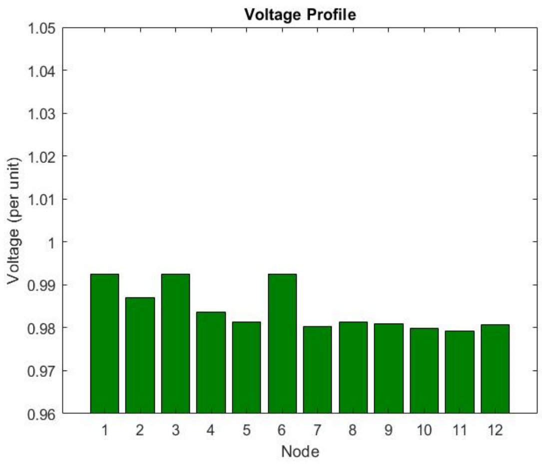
Distribution grid model



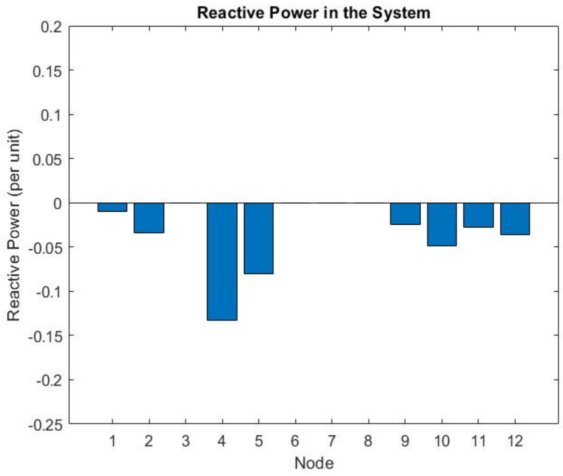
IEEE 13 Node Test Feeder

- A 4.16kV single-feeder radial distribution grid of N+1 nodes and N lines is modeled.
- Distributed Energy Resources (DER) are connected to 9 nodes out of the 12 nodes.
- Measurements are taken from Pecan St dataset
- Node 11 has a 100 kVAR capacitor bank connected and Node 12 has a 200 kVAR connected

Case Study



Voltage at each node

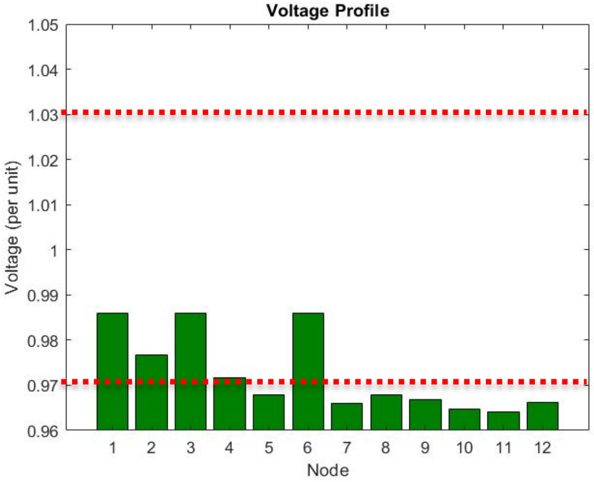


Reactive power at each node

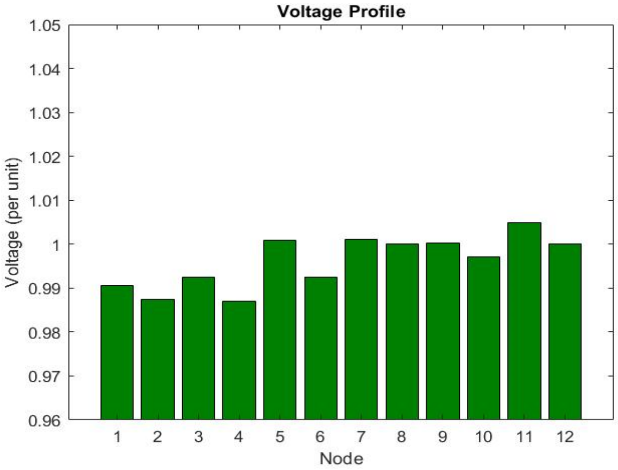
- Initial voltage and reactive power

Case Study

Simulation Case 1



Voltage profile without controller implemented during load increase

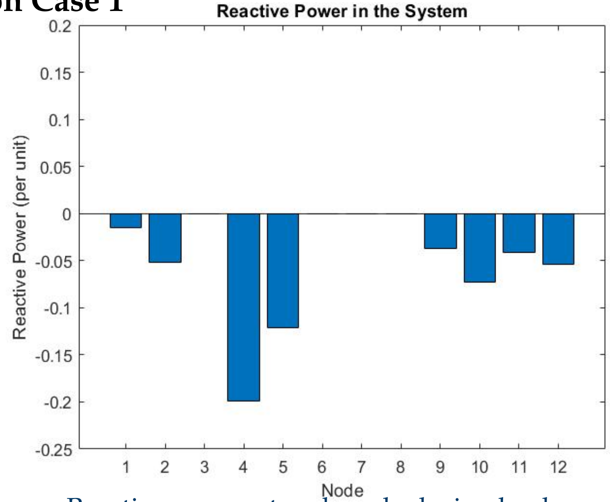


Voltage of profile with controller implemented during load increase

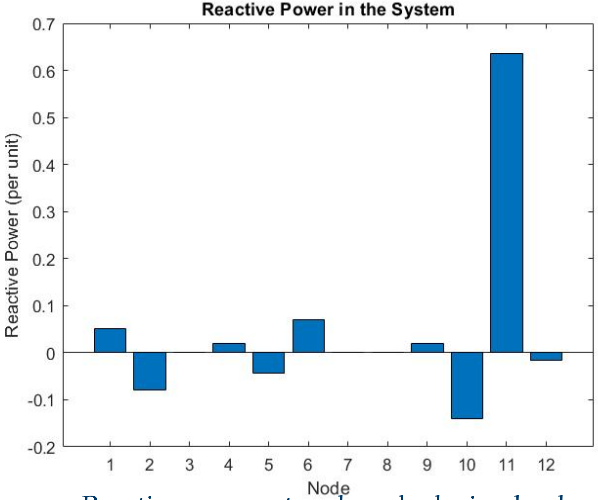
- High customer demand
- The power consumed in the entire system is increased by 50%, causing a voltage dip

Case Study

Simulation Case 1



Reactive power at each node during load increasing without a controller

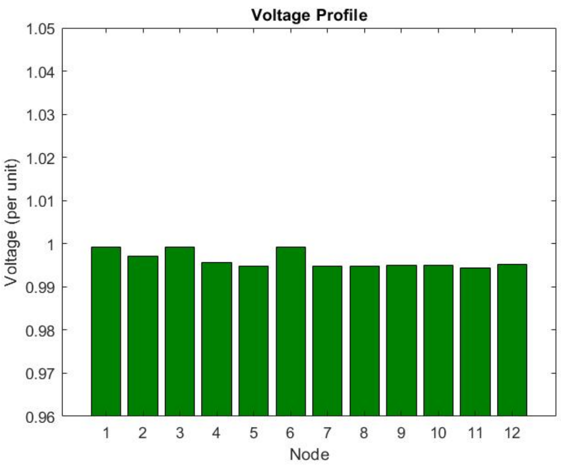


Reactive power at each node during load increasing with a controller

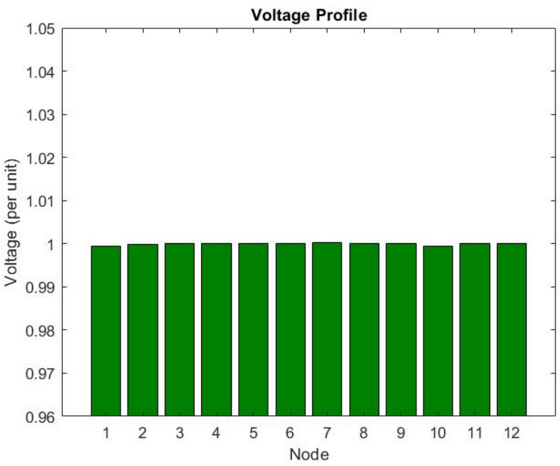
- The amount of reactive power absorption decreases to mitigate the voltage deviations.
- The capacitor bank at node 11 is switched on because the closest inverter has reached the maximum level of reactive power output capacity

Case Study

Simulation Case 2



Voltage profile during load decrease with no controller



Voltage profile during load decrease with a controller

- The active power consumed in the entire system is decreased by 50% and the reactive power consumed is calculated based on the randomized power factor from 0.85-0.9
- With the controller the voltage has a maximum of 0.5% error

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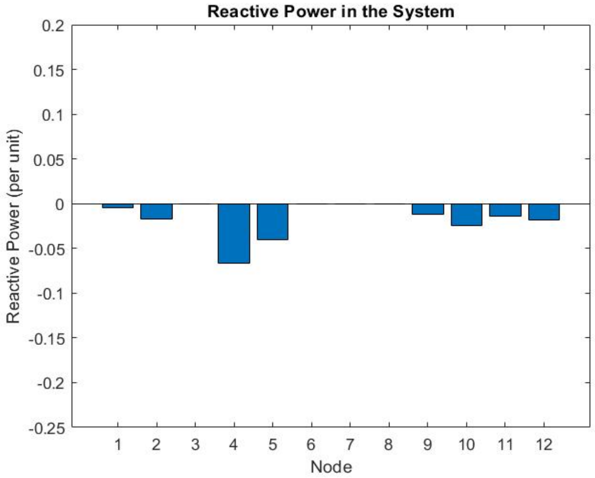
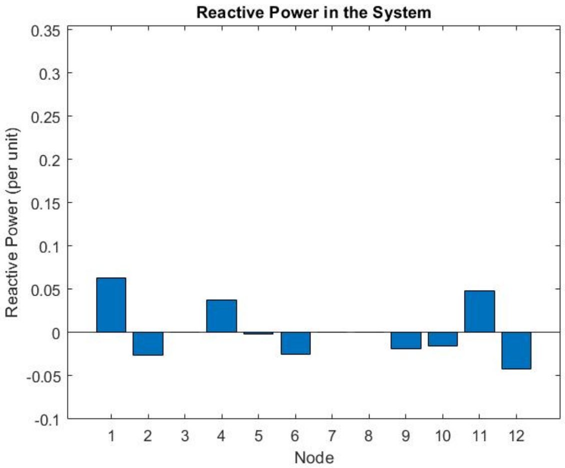
Case Study

Simulation Case 2



Reactive power at each node during load decreasing without a controller



Reactive power at each node during load decreasing with a controller

- Both capacitors lower the amount of injected reactive power because there is a rise in voltage

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Conclusion

☑ The proposed computational method is validated because the voltage deviation remained within range

☑ An optimal solution to turn on/off the capacitor bank was found

Future Work

☑ Applying the Volt/Var method to the Dominion Energy system and analysing the results

☑ Reduce the amount of inverter-based DER in the system and incorporate a transformer load tap changer

Limitations

☑ Doesn't evaluate the performance of other VVC devices such as transformer load tap changer and voltage regulators

Questions

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