UNIVERSITY OF WASHINGTON
ELECTRICAL ENGINEERING

Assessment of Plug-in Electric Vehicles Charging on Distribution Networks

Master Thesis Defense - Tsz Kin (Marco) Au

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Presentation Outline

I. Introduction of PEV
II. The developed tool for investigating the impact of PEV
III. Test system characteristic
IV. Test result
V. Conclusion

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Technological Impacts of PEVs

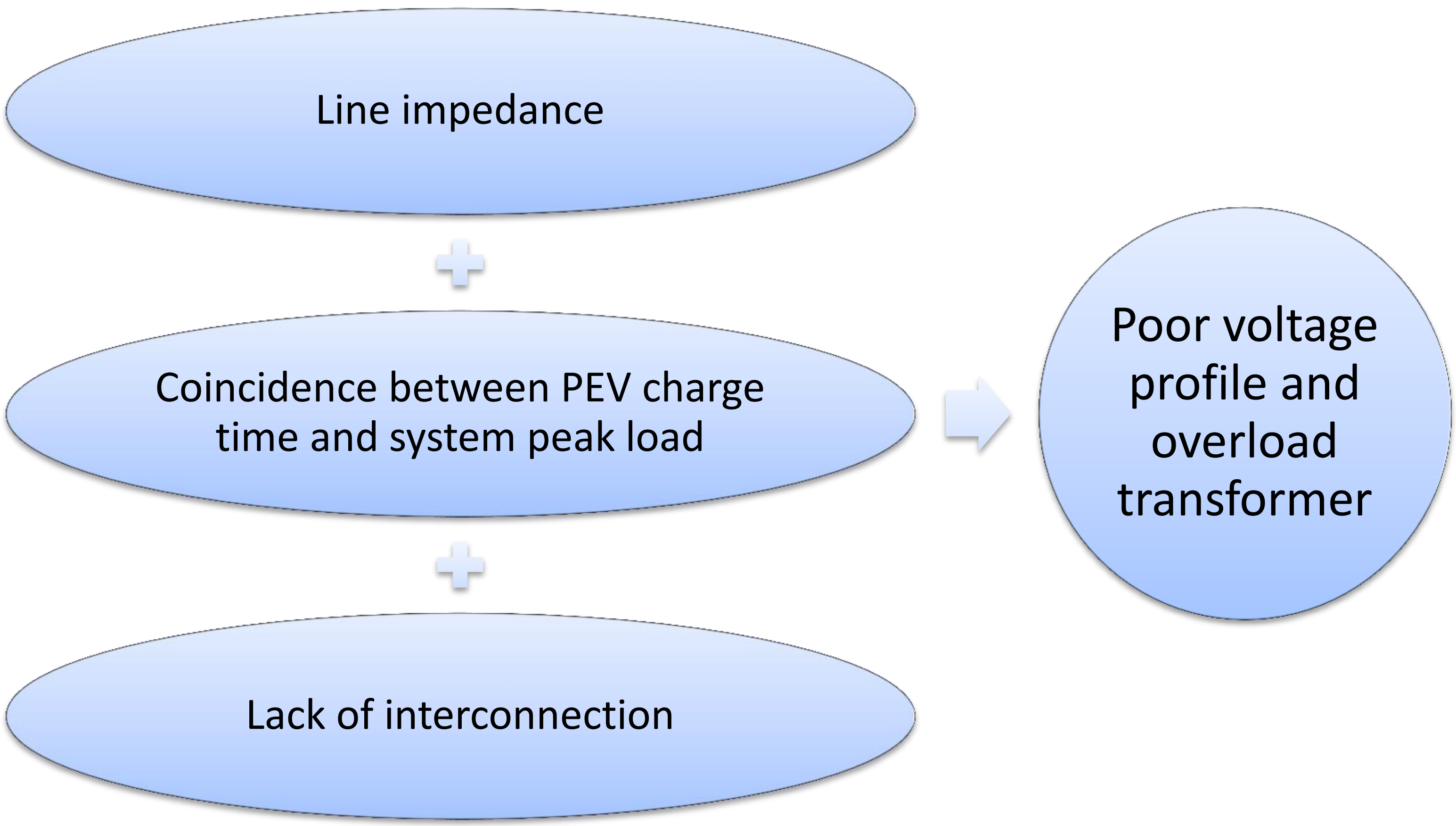
Potential benefits:

- Lower operating cost than combustion engine vehicles: 3.7 vs. 16.7 cents
- On road CO_2 emission will be lower
- V2G and ancillary services provide business opportunities

Problems:

- 10% penetration = additional 300 GWh per day in the U.S.
- Increase grid losses
- Reduce system spare generation and harder to schedule maintenance
- Poorer voltage profile and transformer overloading in weakly meshed distribution networks

What causes poor voltage profile and transformer overloading?



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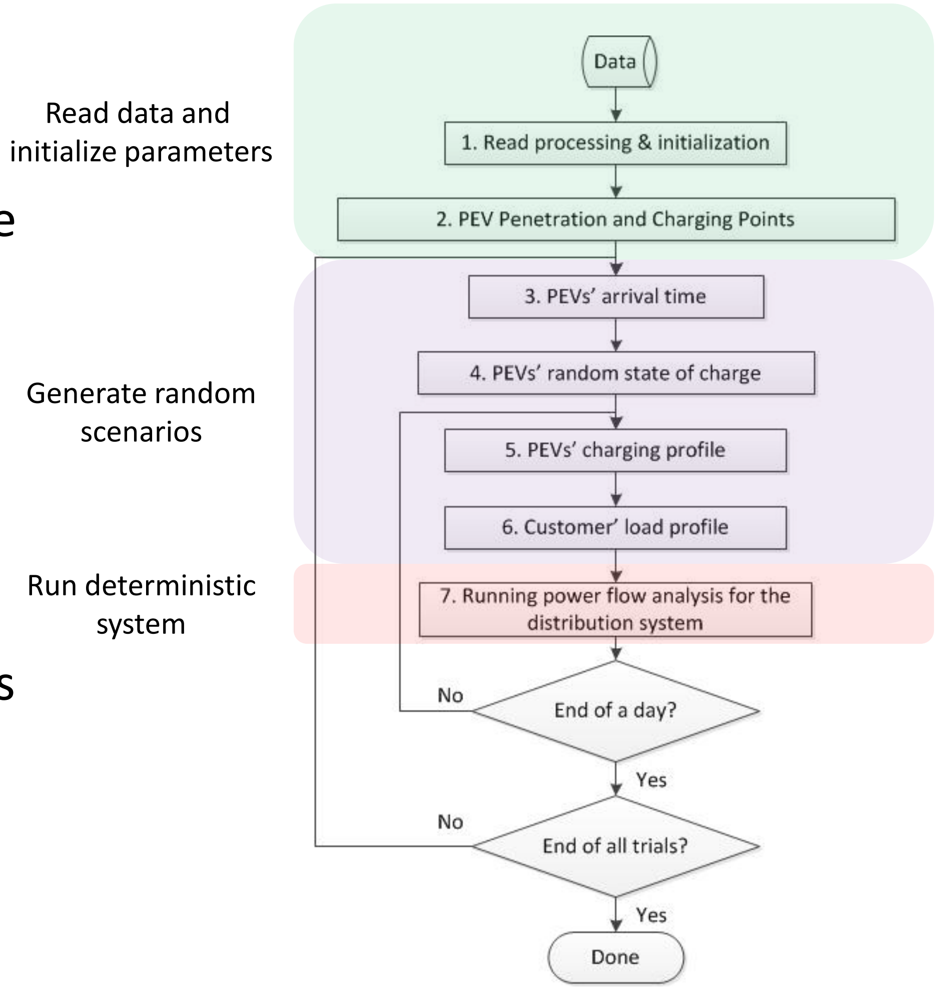
Monte Carlo Simulation

- Suitable for analysis when uncertainties present
- 4 uncertainties needed to be address:
  - Charging time
  - Battery state of charge (SOC)
  - Charging method
  - Customer load variation
- 7 major functional blocks
- Each trail represent 24 hours

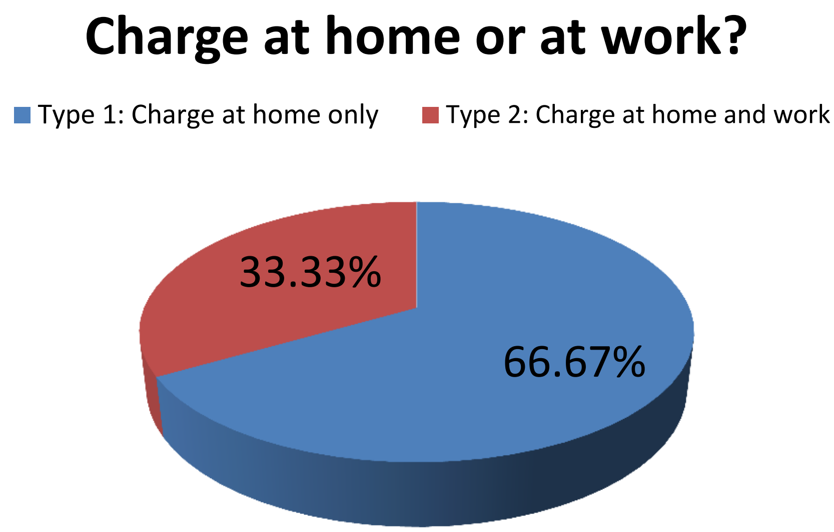


1. Data Processing and Initialization

- 34,000+ drivers' behavior from CMAP, which consists of their to-work and to-home arrival times.
- Electric vehicle parameters
  - Battery capacity
  - Energy consumption per unit distance
- Distribution network conductor parameters
- Average power consumption and load type at each node
  - Residential area
  - Commercial area

2. PEV Penetration and Charging Points

$$PEV\ Penetration = \frac{Total\ number\ of\ passenger\ PEV}{Total\ number\ of\ passenger\ vehicles}$$



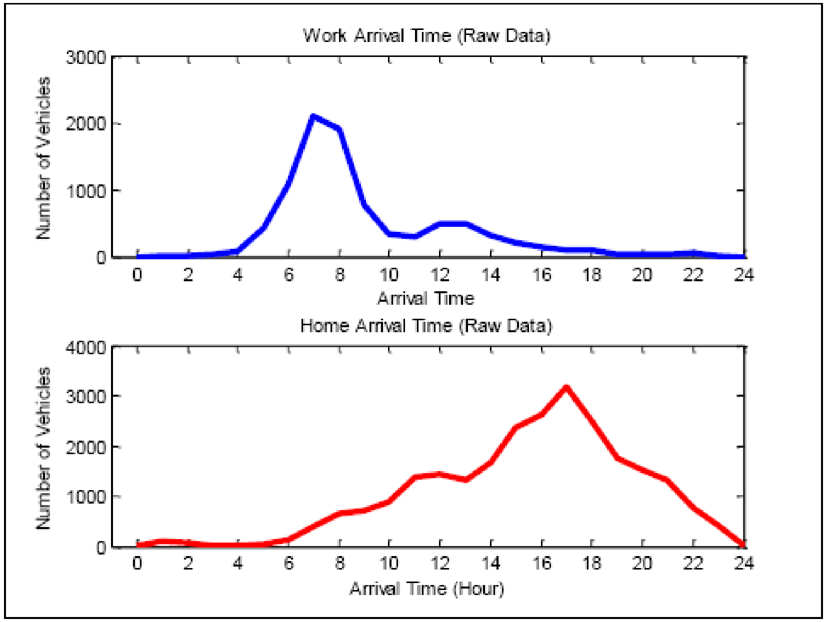
3. PEV's Arrival Time

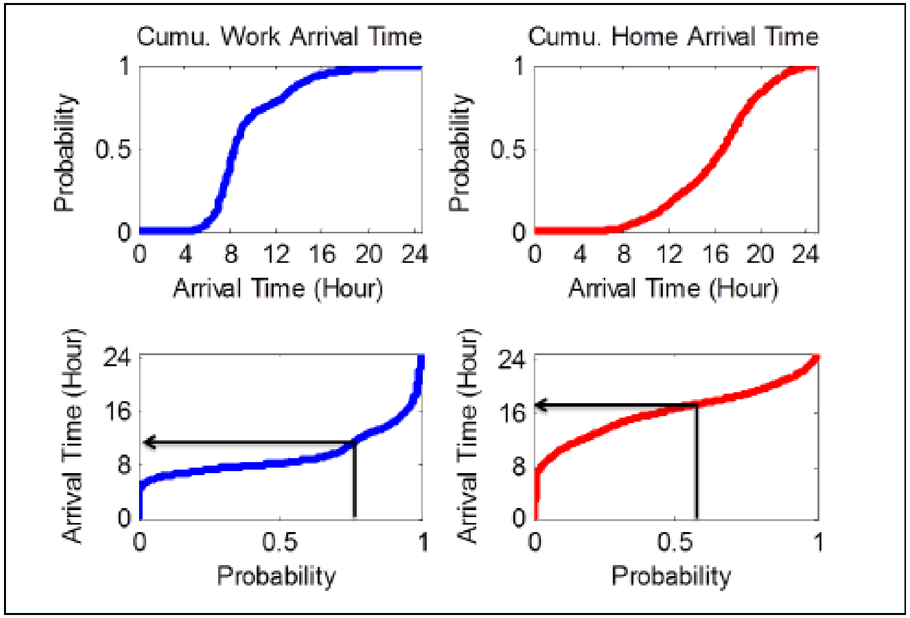
- PEV drivers will charge their vehicles anytime at their convenience
- Their arrival times affect the charge profile
- Drivers' behaviors varies from day to day, which creates uncertainty
- Must model the uncertainty in order to simulate its effect to the power system

3. PEV's Arrival Time

Inverse transformation for random number generation

- Map *rand(0,1)* → actual distribution





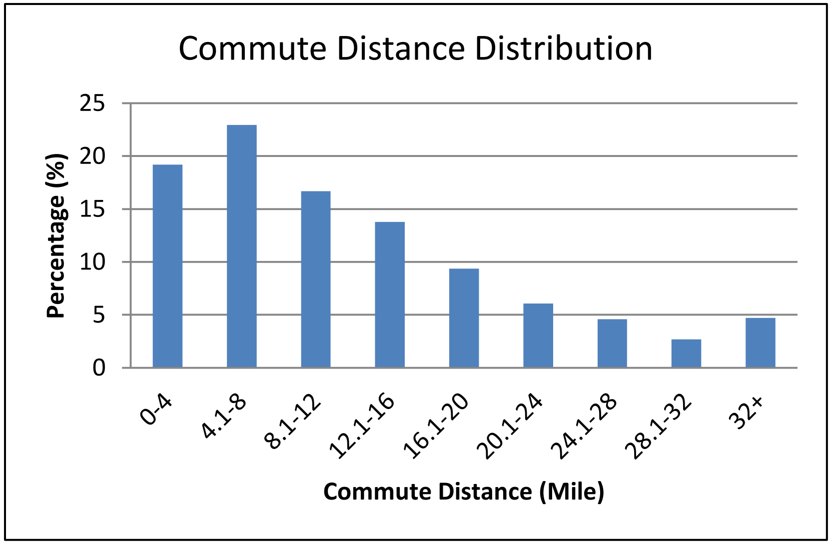
4. PEV's Battery State of Charge

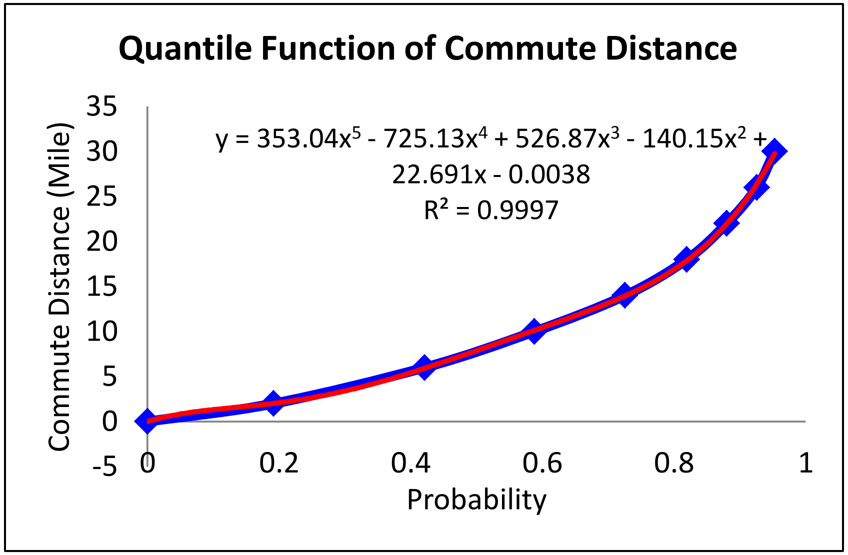
- Commute distance have an effect on the battery state of charge
- A driver's commute distance although is similar everyday, it may vary sometime, which causes uncertainty
- Must model this uncertainty in order to simulate its effect to the power system
- Convert commute distance to battery state of charge (SOC)

$$SOC = Battery\ Cap.(kWh) - Commute\ Dist.(mile) \times 0.34\ kWh/mile$$

4. PEV's Battery State of Charge

Commute distance (miles)	Percentage (%)
0 – 4.0	19.19
4.1 – 8.0	22.95
8.1 – 12.0	16.67
12.1 – 16.0	13.77
16.1 – 20.6	9.37
20.1 – 24.0	6.07
24.1 – 28.0	4.59
28.1 – 32.0	2.69
32.1 +	4.70

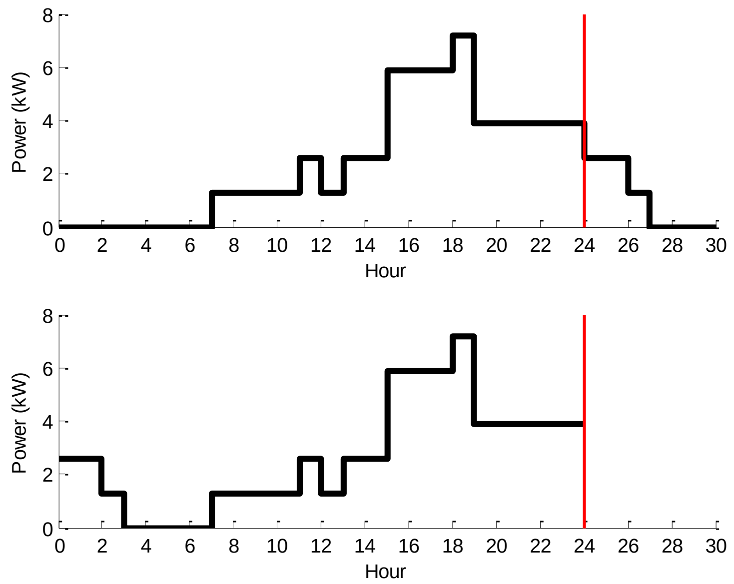




5. PEV Charge Profile

- Computed individually based on arrival time, battery state of charge, and charging method

$$Total\ Charge\ Profile_{hr} = \sum_{i}^{\#\ of\ PEV} P_{i,hr}$$

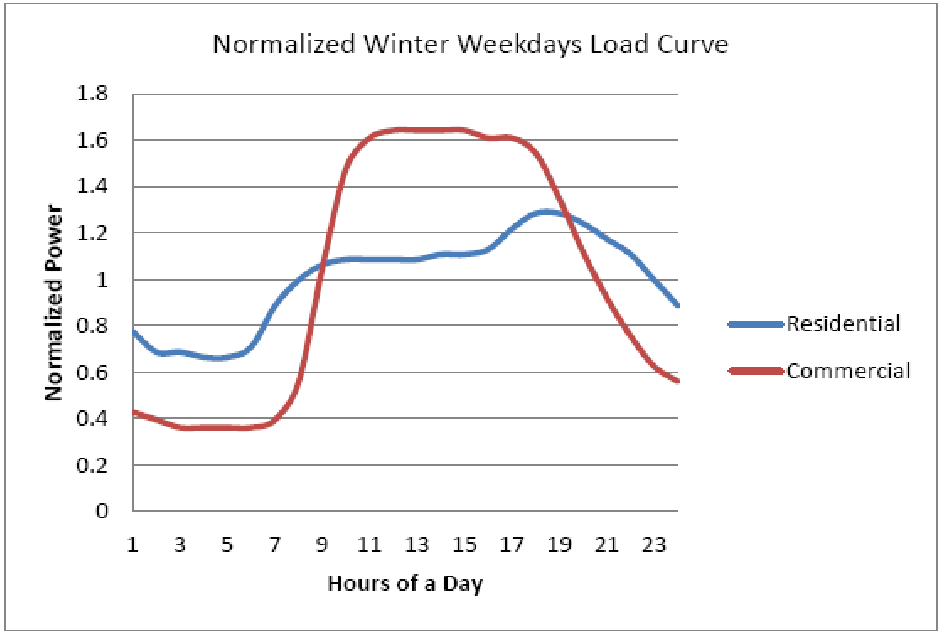


6. Customer Load Profile

- Varies from day to day
- The variation is assumed to be Gaussian distributed:

$$f(P_{bus,ti}) = \frac{1}{\sigma_{bus,ti}\sqrt{2\pi}} e^{-\frac{1}{2}\cdot\frac{(P_{bus,ti}-AvgP_{bus,ti})}{\sigma_{bus,ti}^2}}$$

$$AvgP_{bus,ti} = P_{type,ti}^{norm} \times AvgP_{bus}$$

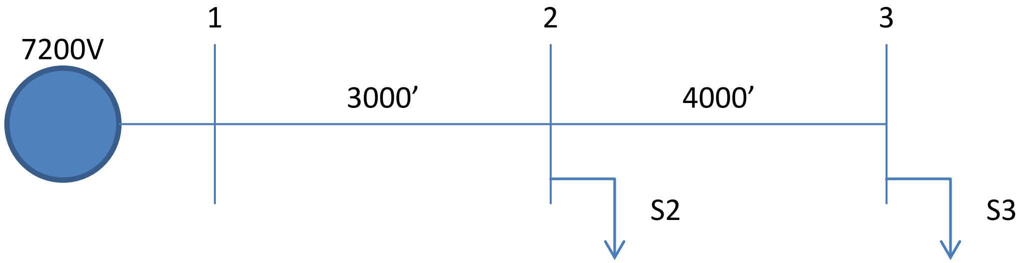


7. Running Power Flow Analysis for the Distribution System

- Cannot use Newton-Raphson based methods
- Distribution networks characteristic:
  - High R/X ratio → Decoupled and fast decoupled methods won't work
  - Weakly meshed, sparse network → Newton-Raphson method won't work
- Forward-backward sweep method is used

7. Running Power Flow Analysis for the Distribution System

Forward-backward sweep method example:



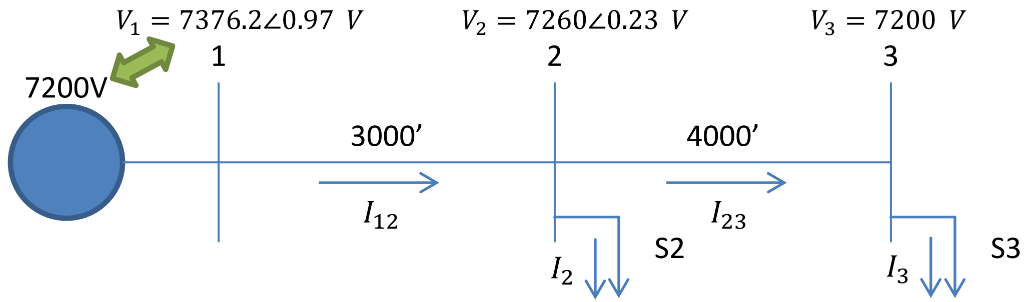
$$z = 0.3 + j0.6 \;\; \Omega/mile$$

$$z_{12} = 0.1705 + j0.3409 \;\; \Omega$$
$$z_{23} = 0.2273 + j0.4545 \;\; \Omega$$

$$s_2 = 1500 + j750 \;\; kW + jkVar$$
$$s_3 = 900 + j500 \;\; kW + jkVar$$

7. Running Power Flow Analysis for the Distribution System

Forward-backward sweep method example:



Forward sweep:

1) Assume voltage at node 3 is 7200V

2) Compute I_3

$$I_3 = \left(\frac{S_3}{V_3}\right)^* = 143.0\angle -29.0\ \ A$$

3) Compute I_{23}

$$I_{23} = I_3 = 143.0\angle -29.0\ \ A$$

4) Compute V_2

$$V_2 = V_3 + Z_{23} \cdot I_{23} = 7260.1\angle 0.23\ \ V$$

5) Compute I_2

$$I_2 = \left(\frac{S_2}{V_2}\right)^* = 231.0\angle -26.3\ \ A$$

6) Compute I_{12}

$$I_{12} = I_{23} + I_2 = 373.9\angle -27.3\ \ A$$

7) Compute V_1

$$V_1 = V_2 + Z_{12} \cdot I_{12} = 7376.2\angle 0.97\ \ V$$

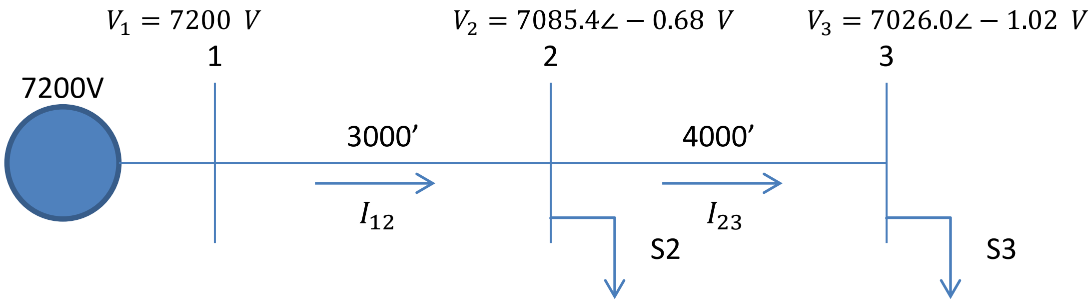
8) Compute mismatch between V_1 and V_s

$$Mismatch = \big||V_s| - |V_1|\big| = 176.2\ \ V$$

Not satisfy!

7. Running Power Flow Analysis for the Distribution System

Forward-backward sweep method example:



Backward sweep:

1) Assume voltage at node 1 is 7200V, and use the line currents computed from forward sweep

2) Compute V_2

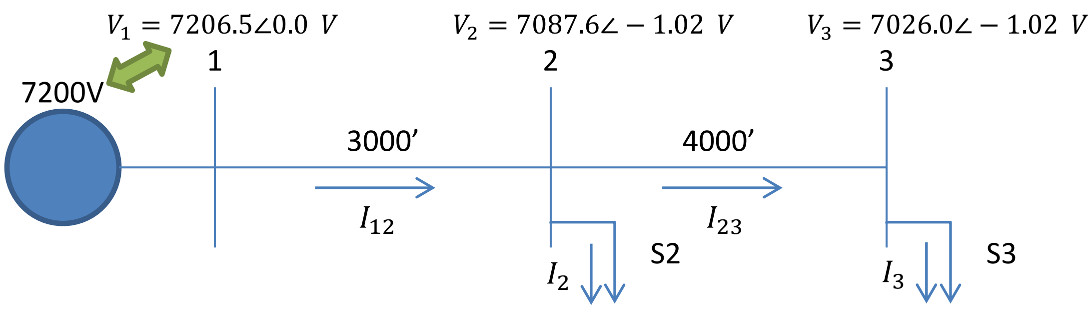
$$V_2 = V_1 - Z_{12} \cdot I_{12} = 7085.4\angle -0.68\ V$$

3) Compute V_3

$$V_3 = V_2 - Z_{23} \cdot I_{23} = 7026.0\angle -1.02\ V$$

7. Running Power Flow Analysis for the Distribution System

Forward-backward sweep method example:



Perform forward sweep again:

1) Use the voltage at node 3 from the backward sweep

2) Compute I_3

$$I_3 = \left(\frac{S_3}{V_3}\right)^* = 146.5\angle -30.1\ A$$

3) Compute I_{23}

$$I_{23} = I_3 = 146.5\angle -30.1\ A$$

4) Compute V_2

$$V_2 = V_3 + Z_{23} \cdot I_{23} = 7087.6\angle -1.02\ V$$

5) Compute I_2

$$I_2 = \left(\frac{S_2}{V_2}\right)^* = 236.6\angle -27.2\ A$$

6) Compute I_{12}

$$I_{12} = I_{23} + I_2 = 383.0\angle -28.3\ A$$

7) Compute V_1

$$V_1 = V_2 + Z_{12} \cdot I_{12} = 7206.5\angle 0.0\ V$$

8) Compute mismatch between V_1 and V_s

$$Mismatch = \big||V_s| - |V_1|\big| = 6.535\ V$$

Satisfy!

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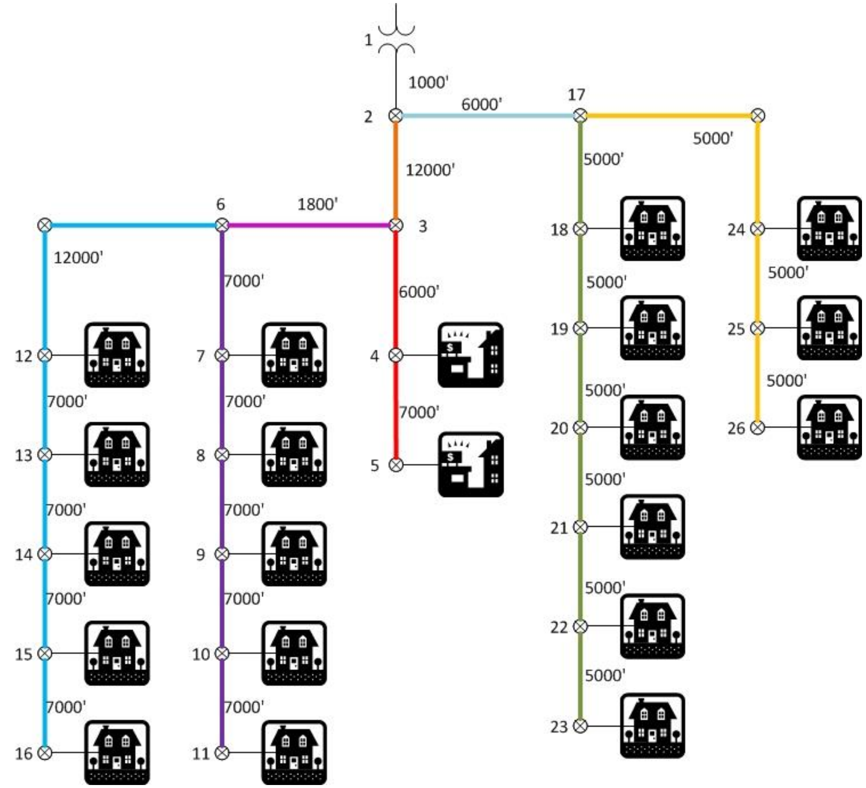
Test System Characteristic

Assumption:

- 4000 residents
- Average 2.35 people and 1.78 passenger vehicles per household
-  power factor = 0.9
-  power factor = 0.8
- Avg. 959.5 W/household
- Average power consumption:

 = 81.6 + 40.8j (kW+kVar)

 = 100 + 75j (kW+kVar)



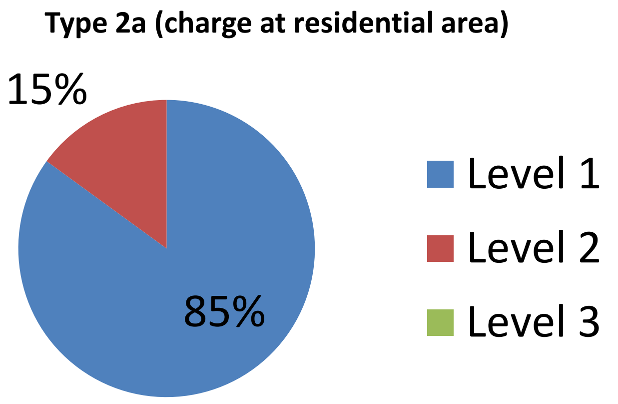
 = residential area = 85 households

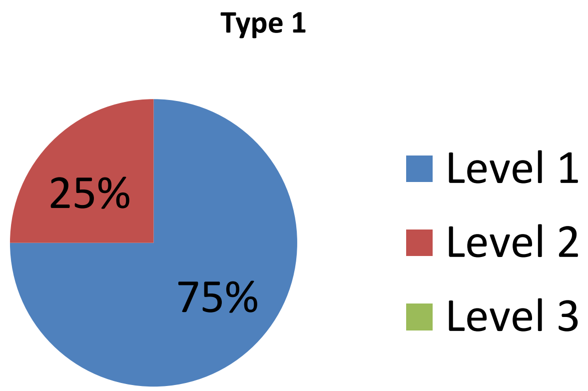
 = commercial area = 1 small shopping plaza

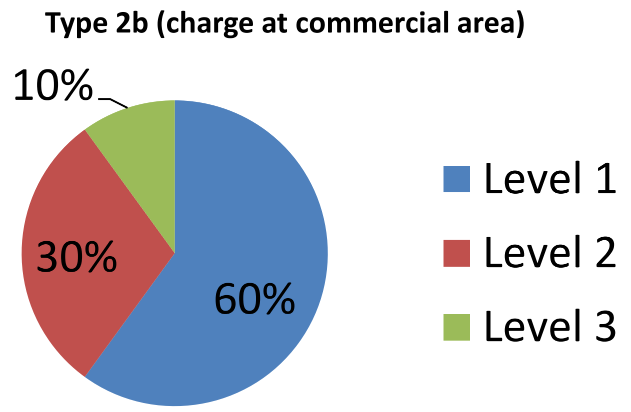
Test System Characteristic

Charging method and scenario:

- Level 1: 1.3 kW
- Level 2: 3.3 kW
- Level 3: 50 kW







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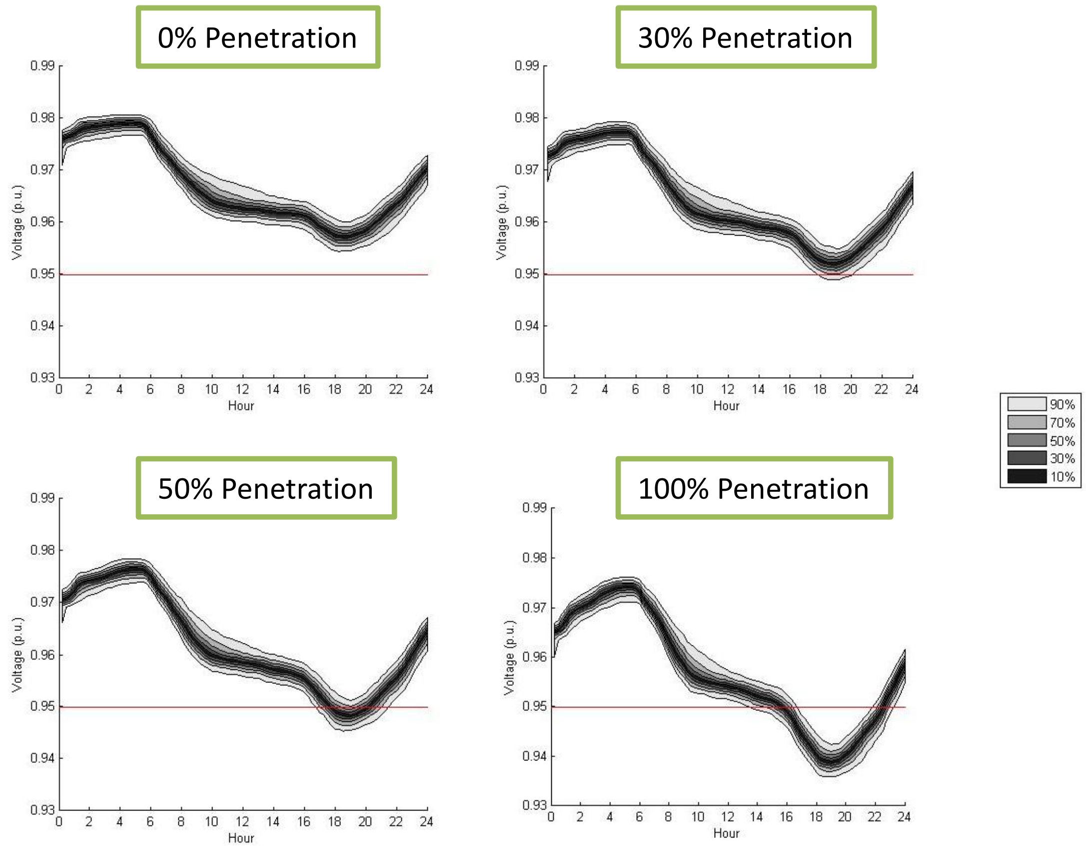
Test Result: Voltage Violation

Voltage Profile

- Voltage should operate ±0.05 p.u.
- Voltages at the End Buses have higher chance to suffer low voltage violation

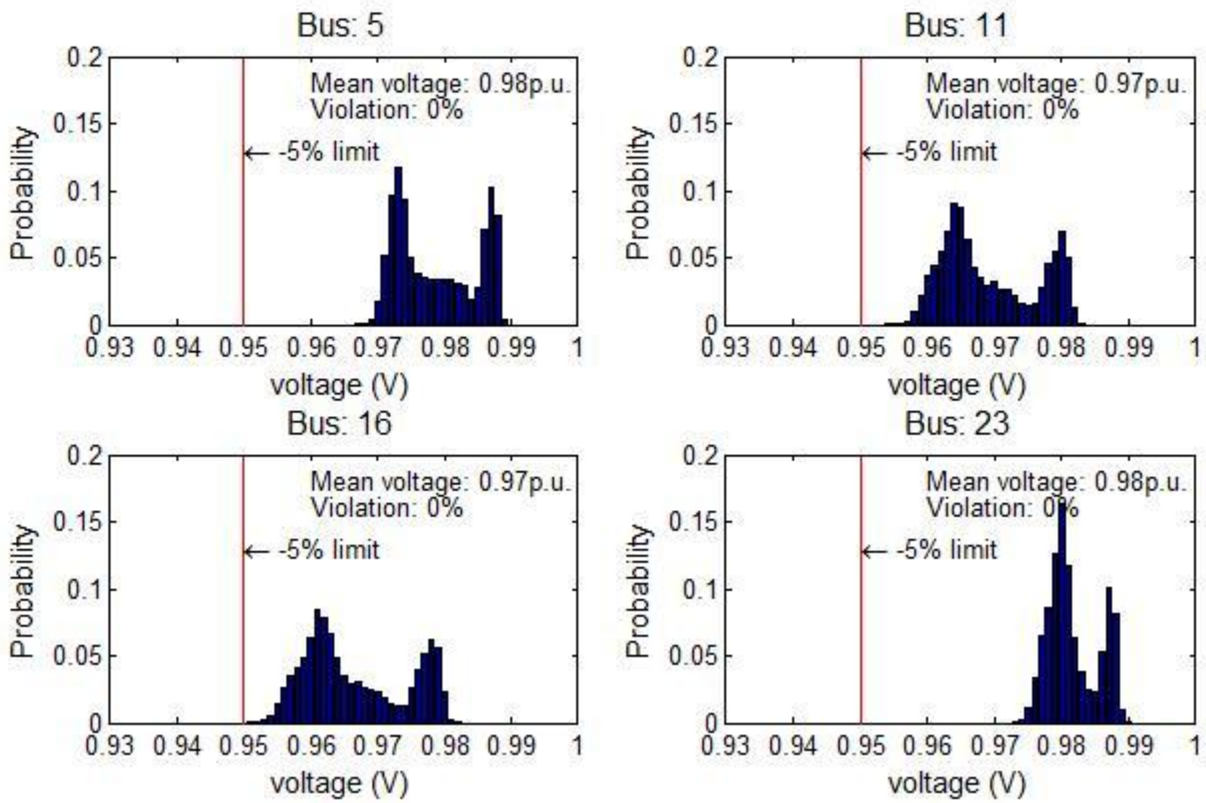
Test Result: Voltage Violation

Voltage profile confidence interval at bus 16



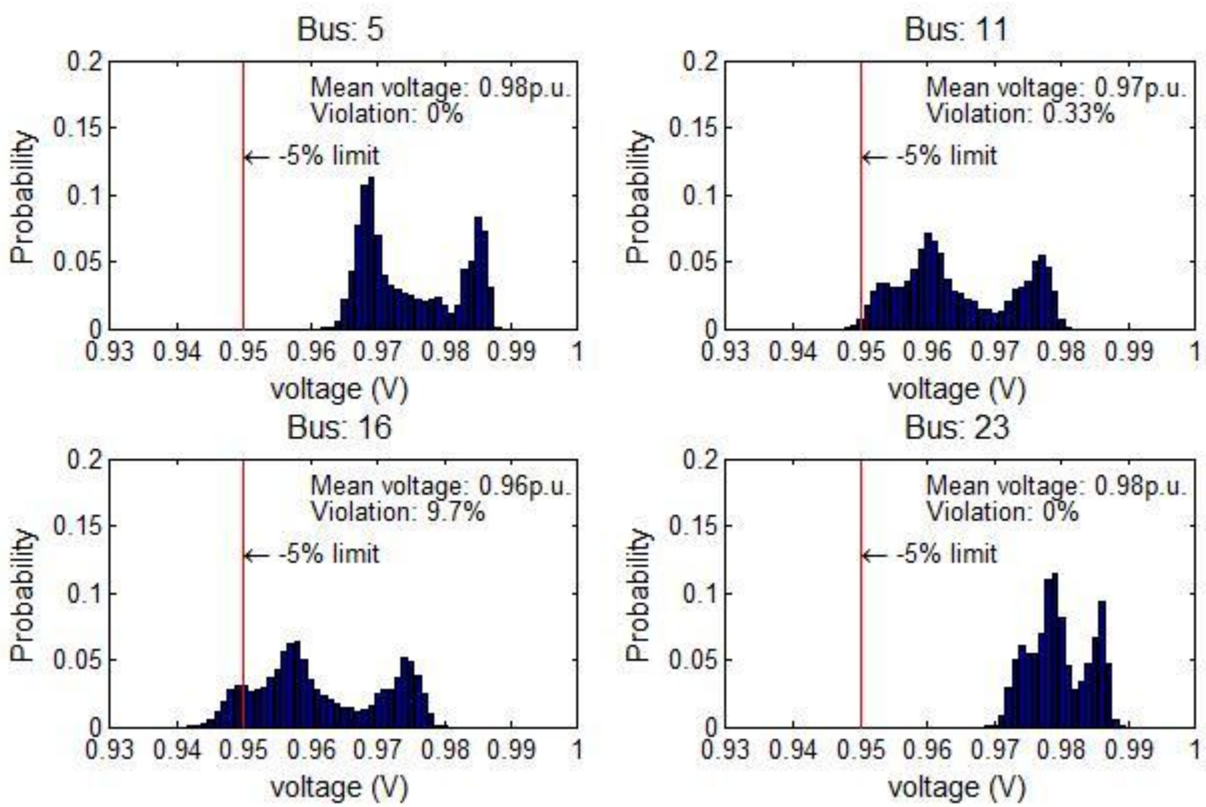
Test Result: Voltage Violation

Voltage distribution for 0% Penetration Scenario



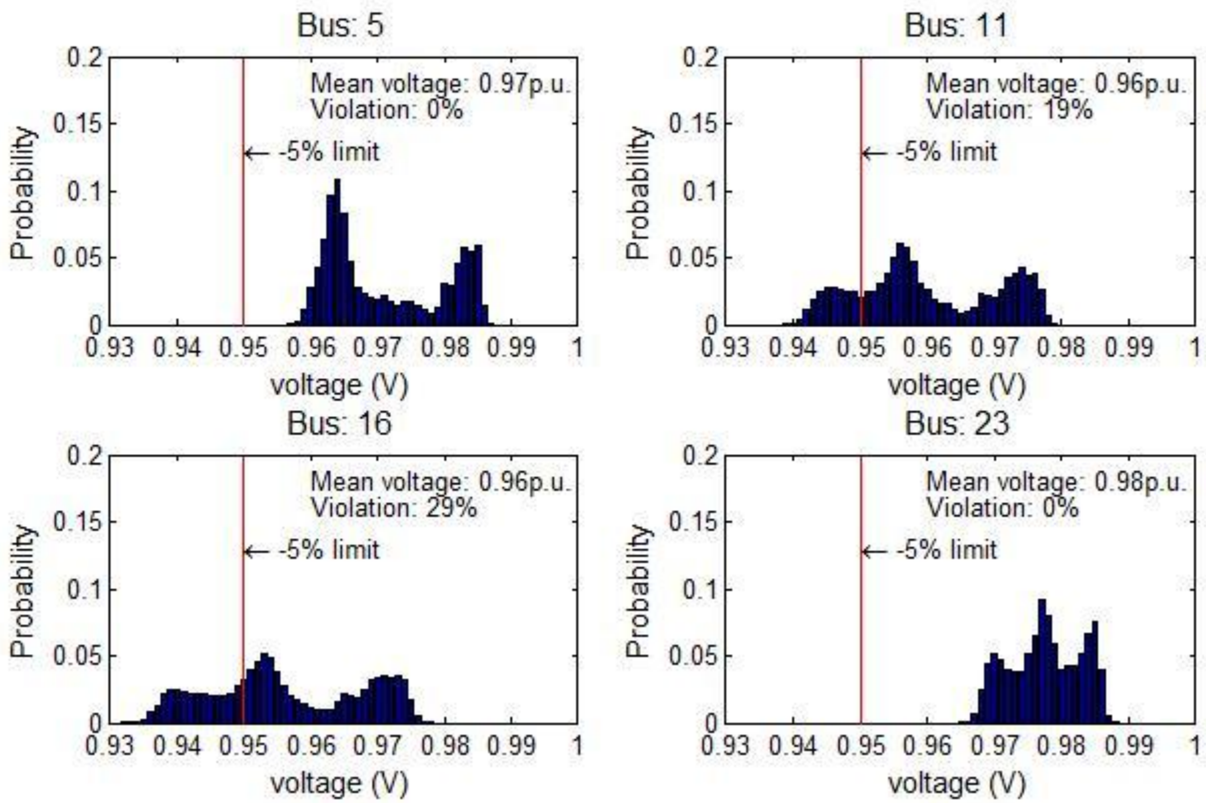
Test Result: Voltage Violation

Voltage distribution for 50% Penetration Scenario



Test Result: Voltage Violation

Voltage distribution for 100% Penetration Scenario

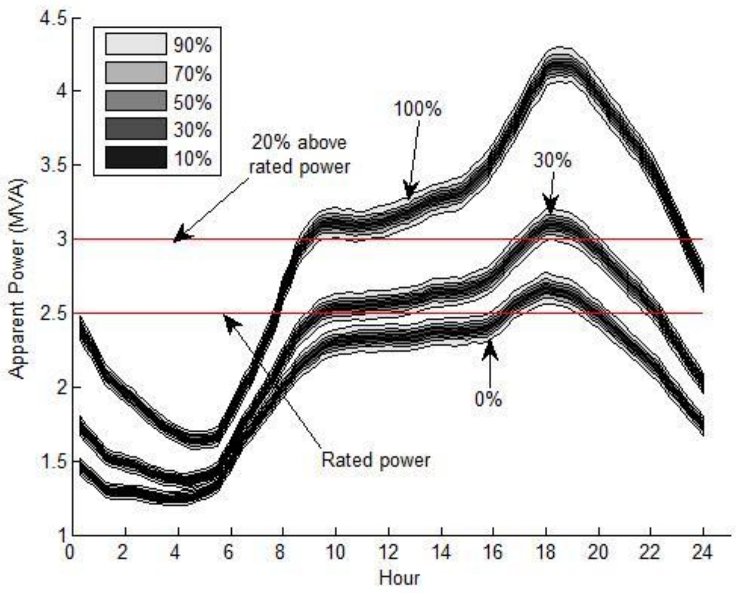


Test Result: Transformer Load

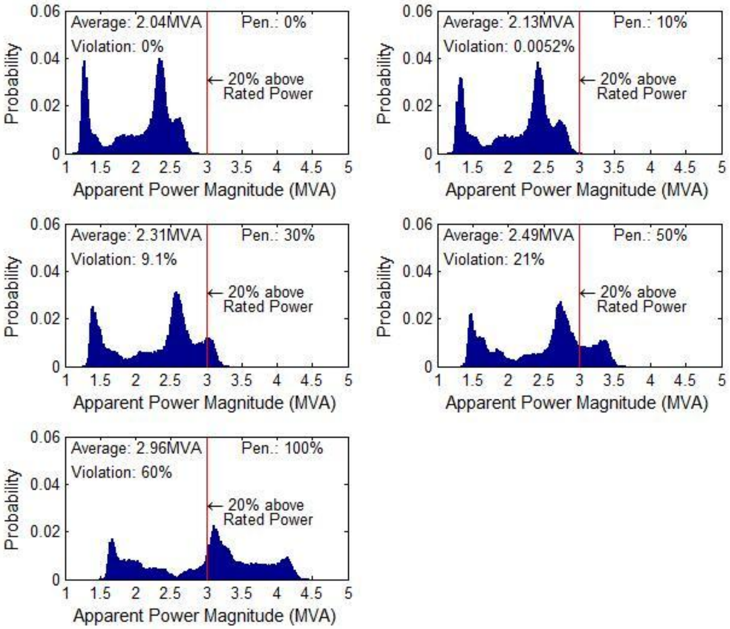
- Although transforms usually can be overloaded for short period of time with limited amount, overloading it by too much or too long will decrease its life time
- Transformer overloaded: loaded above its capacity
- Transformer violation: loaded 20% above its capacity

Test Result: Transformer Load

Transformer load profile



Transformer load distribution



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Conclusion

- Electricity for transportation? Yes or No?
- PEVs impacts vary from system to system
  - Voltage violation: long radial networks
  - Substation transformer violation: Heavy load, high PEV penetration
- A tool to evaluate PEVs impacts is developed

Thank you!