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Electric Vehicle Dynamic Wireless Charging Load Profile and System Sizing for Highways

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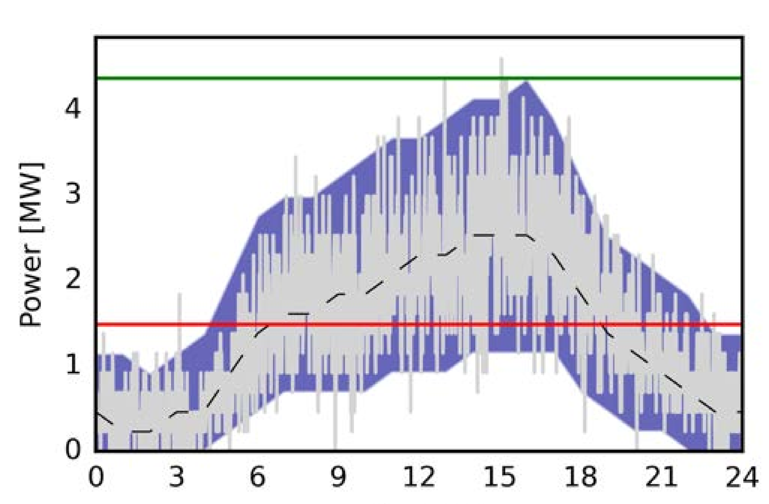
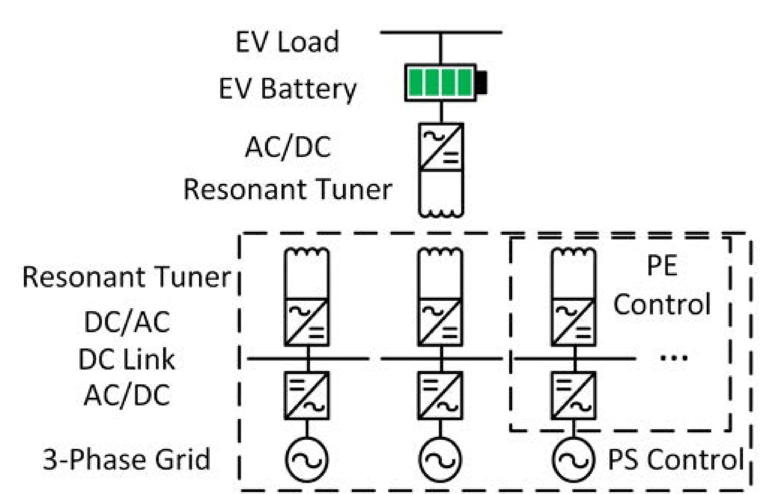
Introduction and Major Contributions

- Parametric studies for accurate load modeling considering location-specific traffic behavior for dynamic wireless charging (DWCS) of electric vehicles (EV) on a roadway
- Distribution-level simulation using OpenDSS co-simulation comparing distributed and centralized interconnection with variation of synthetic traffic sensing resolution for highly variable demand, assuming 100% user uptake

Traffic-Based Load Modeling for DWCS

- DWCS charge EVs in motion at full speed using electromagnetic coupling and is controlled by an aggregate operator and grid-side power electronics in response to traffic behavior on the roadway
- Due to the location-specific traffic dependency, system load relies heavily on vehicle speed, number, and the size of the system, varying greatly at the MW-level
- The traffic data used in this study was provided by the Kentucky Transportation Cabinet for I-70 between Bowling Green, KY, and Nashville, TN (long-distance focused)
- Python scripts were developed to emulate vehicles entering the roadway with a duration related to their initial speed and the length of the DWCS roadway section (1 mile).



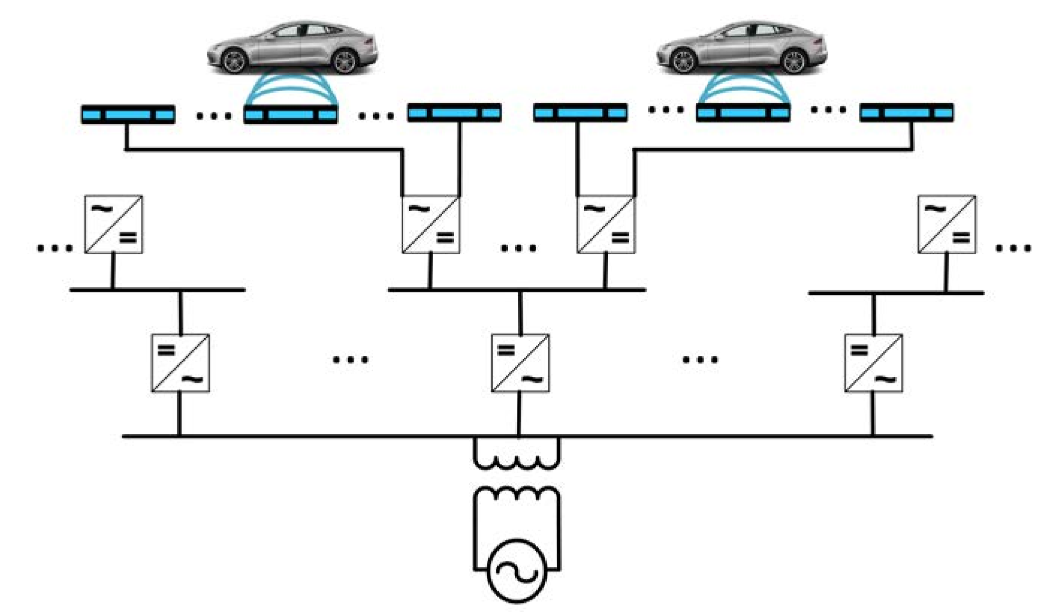


$$V_a(n) = \frac{e^{-\lambda * t} * (\lambda * t)^n}{n!} \quad \text{where } \lambda = V_a(h) * \Delta(t)$$

$$S_v(V) = \frac{1}{\sigma\sqrt{2\pi}} * e^{-\frac{1}{2}\left(\frac{V-\lambda}{\sigma}\right)^2}$$

Traffic-based System Segmentation

- Estimated synthetic traffic load can be used for the sizing of components and determination of interconnection within the larger system to capture the majority of expected power
- Converter utilization can be approximated from the power load profile and the maximum power necessary for majority of the load
- Coil units can be segmented s.t. multiple coils are connected to a single inverter, reducing system cost
- Spatial density analysis was used to approximate the maximum number of coils per coil section depending on traffic load
- System segmentation can increase converter utilization from 3% to as much as 31% on this roadway, greatly reducing costs



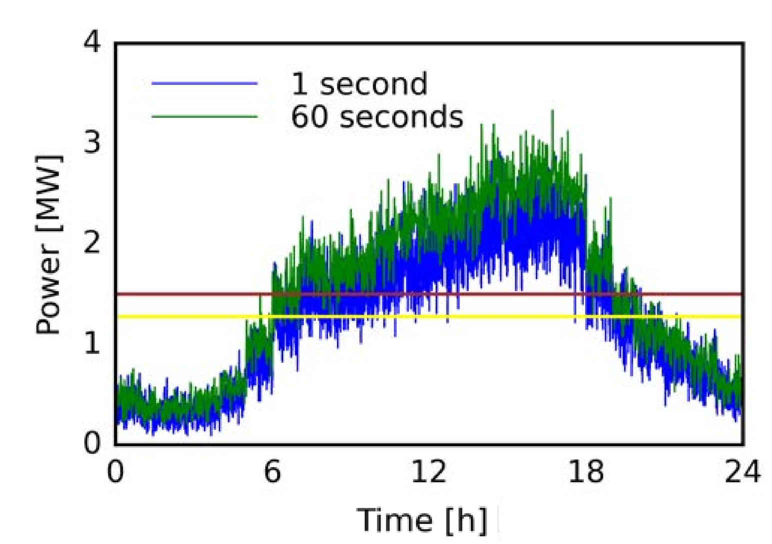
$$k = \frac{V_{num}}{\frac{T_L}{V_L}} \qquad C_{act} = \frac{k}{C_L}$$

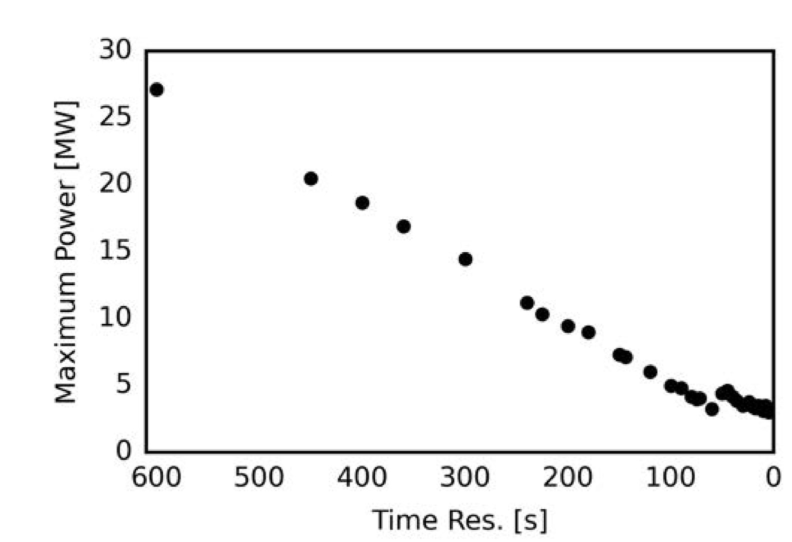
$$C_{sec} = \frac{C_{num}}{max(C_{act})}$$

$$PE_{act} = \frac{C_{act}}{\frac{C_{num}}{C_{sec}}}$$

Synthetic Traffic Density Analysis with Accurate Sensing

- Daily load profiles are highly dependent on the number of vehicles traveling across the roadway at any point in time
- The density of vehicles on the roadway can greatly increase load during peak hours and is affected by speed-related traffic jams
- When lacking high-resolution traffic data, we can generate an approximation of traffic load by stochastically interpolating the time of arrival
- Hourly Annual Average Daily Travel (AADT) used in this study is provided by the Kentucky Transportation Cabinet with sensing along I-70 between Bowling Green, KY, and Nashville, TN
- Unlike traditional traffic modeling where hourly data is sufficient, the instantaneous nature of power demand, and very small active window of coil activation, necessitates second-level resolution
- Comparing 1 second to 60 second resolution, maximum power expected decreases by 21% and average power decreases by 16%.

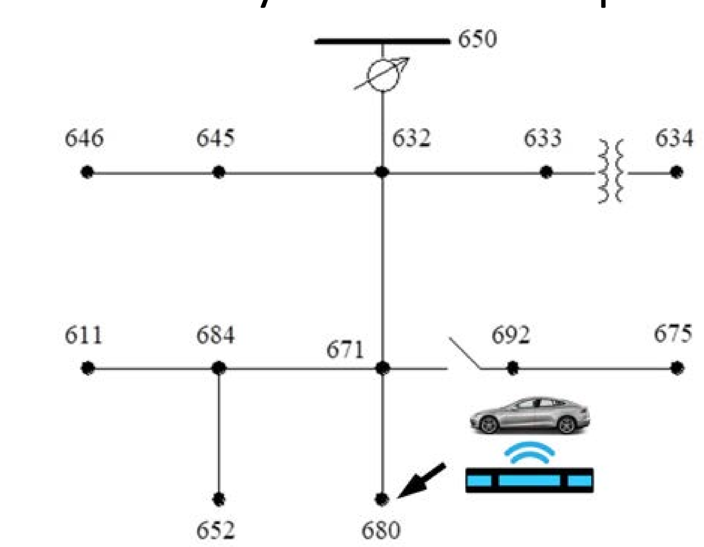


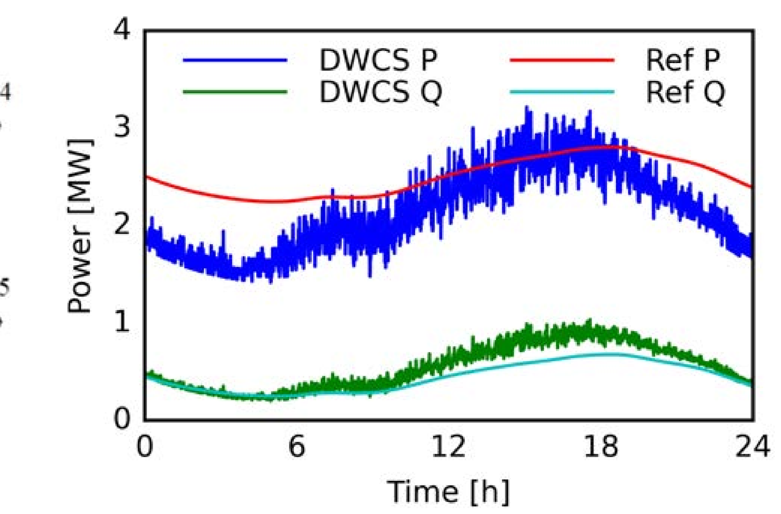


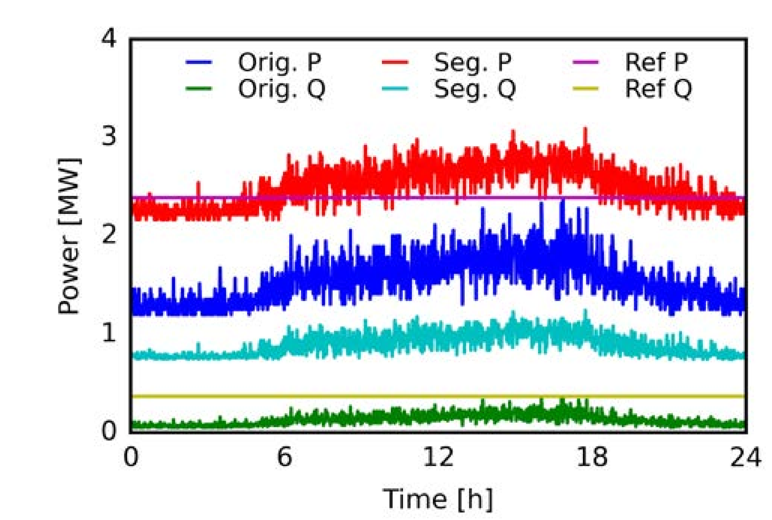
Timestep (s)	Average Power [MW]	Maximum Power [MW]	Aggregate Power [MW]	Power Ripple [MW]
60	1.5	3.7	2176.3	3.6
30	1.5	3.4	2142.2	3.3
15	1.5	3.4	2124.2	3.3
1	1.3	3.1	1842.4	3.0
0.25	1.3	3.0	1836.1	3.0

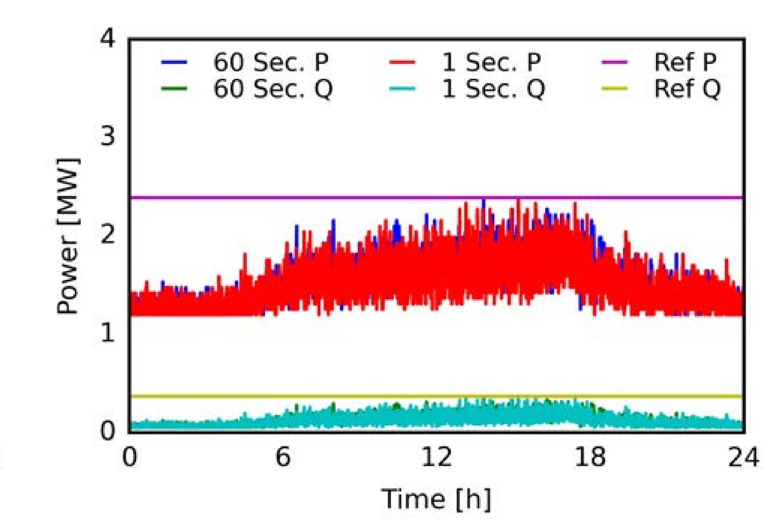
Case Study – Aggregate Load on IEEE 13-Bus Network

- OpenDSS by EPRI is employed as an electric power distribution system simulator to study grid integration
- A modified IEEE 13-bus distribution system was modeled with an added aggregated DWCS load scaled to and replacing the largest system load
- Power flow solution with added DWCS showcases increased variability in voltage and power.
- Initial segmentation simulation shows increased power necessary when load is split in ½ and separated by ½ a mile









Conclusions

- System segmentation can be improved overall utilization by 30%. Initial power system simulation shows 23% larger power demand within a spatially distanced segmented system
- Resolution of available traffic data or synthetic interpolation greatly alters system sizing. Maximum power varies by as much as 21% with average power varying by as much as 16%. Aggregate results of power system simulation vary by 20%.

Future and Ongoing Work

- Continued development of power system simulation of segmentation for interconnection planning
- Comparison of feasibility for a mixture of static and dynamic chargers considering costs and power system impact

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