Harnessing electric vehicle demand flexibility: Energy and Power are the Keys!

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Outline

- Promise of vehicle electrification,
- Power versus energy,
- Gas station filling paradigm,
- Drivers of cost in electricity industry,
- Paradigm shift,
- Projections of charging load,
- Energy and power are the keys!

Promise of vehicle electrification

- Reduce use of oil imported from overseas:
  - For the other 47 contiguous states, reduce use of oil imported from Texas!
  - Fracking has significantly increased the domestic supply of natural gas and, more recently, liquids.
- Expanded supply and low price of natural gas has changed the electric generation landscape:
  - In Texas, combined-cycle natural gas generation is currently cheaper to operate than much coal.

Promise of vehicle electrification

- Reduce greenhouse and other emissions:
  - Electric generation generally lower emissions than using gasoline in internal combustion engine (ICE): http://www2.daimler.com/sustainability/optiresource/index.html
  - For electric cars charged off-peak (overnight) in Texas, incremental resource is sometimes wind that has zero variable emissions:
    - Wind blows more overnight in Texas than during day,
    - Wind curtailed when electric load sufficiently low overnight,
    - Plans for increased wind in Texas will increase curtailment at times of low load.

Promise of vehicle electrification

- Several studies have suggested that there is potential for expanding electrical *energy* production in North America to allow for transportation electrification with relatively small, or negligible, expansion of generation, transmission, and distribution infrastructure.
- This promise requires qualification in context of distinguishing energy from power.

Power versus energy

- Power is the rate of doing work or delivering energy:
  - Standard units in electricity are kW and MW,
  - Fixed "exchange rate" with horsepower,
- Energy is the amount of work done or delivered over time:
  - Standard units in electricity are kWh or MWh,
  - Fixed "exchange rate" with Btu.

Power and energy

- Large-scale storage of electricity is relatively costly:
  - Most electric energy is produced essentially simultaneously with its consumption,
  - So, maximum power rating (capacity) of generation, transmission, and distribution system must be sized to cover maximum peak load,
  - Charging an electric vehicle at 4pm requires electricity to be produced at 4pm,
  - Production cost at 4pm typically higher than off-peak.

Power and energy

- In electricity industry average power is much lower than power capacity:
  - Considerable unused capacity available *each night*.
- In contrast, storage of liquid fuels is relatively inexpensive compared to electricity storage:
  - Production of gasoline not as coincident with use,
  - Production capacity of gasoline production sized *closer* to average and operated at more constant level with storage smoothing out demand variation.

Power

- "Charging" a conventional car with gasoline provides about 33.4 kWh of energy per gallon:
  - But efficiency of conversion of gasoline into mechanical energy only around 30%,
  - So effective delivery is about 10 kWh per gallon.
- *Power* transfer for filling a 10 gallon tank in 2 minutes:
  - (10 kWh/gal)×(10 gal)/(2 minutes) = **3 MW**,
- How does that compare to charging plug-in electric vehicles (PEVs)?

Conventional electric vehicle supply equipment (EVSE)

Level I: **1.8 kW**

Level II: **14 kW**

Gasoline is hard to beat for moving energy

Tesla Supercharger: **100 kW**

Filling up the tank:
3 MW = 3000 kW

Power levels of familiar loads

- Typical house has average power level of 2 kW.
- Peak household load in Texas (driven by level of air-conditioning) typically below 10 kW.
- University of Texas main campus peak load is around 50 MW.
- Equivalent maximum power level for just 3 gas stations each with 6 filling bays is more electric load than the whole of UT main campus!
  - There are around 10 gas stations near UT!

Energy

- Approximate typical battery energy capacity:
  - Toyota Prius: 1.2 kWh,
  - Plug-in Prius: 4 kWh,
  - Chevy Volt: 16 kWh,
  - Nissan Leaf: 24 kWh,
  - Tesla Model S: 85 kWh (largest PEV battery).
- A 10 gal gasoline tank can store 100 kWh of equivalent mechanical energy:
  - Many cars have much larger tanks.

Gas station filling paradigm

- Gas station filling relies on being able to deliver a lot of energy in a short time to a car:
  - Delivery power of 3 MW is high.
- Reproducing that paradigm for PEV charging:
  - Battery technology: an order of magnitude behind,
  - Cost of delivery infrastructure: adding multiple 100 kW (or 3 MW) loads will require significant upgrades,
  - Daytime charging: coincident with highest operating cost generation, and inability to use off-peak generation resources.

Gas station filling paradigm

- To summarize, achieving fast charge of electric vehicle with high power is aimed at reproducing paradigm of filling up the tank at gas station:
  - But electric power level needed is much larger than other typical retail end-uses of electricity,
  - Charging at time of peak demand will necessitate generation, transmission, distribution upgrades, and involve high operating cost generation resources.

Drivers of cost in electricity industry

- Commodity cost of electric energy in Texas is less than half of total retail:
  - Retail price significantly above energy cost due to cost of transmission and distribution system.
- PEV charging on-peak:
  - Increased capacity of generation, transmission, and distribution,
- Off-peak charging:
  - Just cost of incremental energy, including wind.

Paradigm shift

- Instead of trying to reproduce gas filling station experience:
  - Charge at home overnight most of the time.
- PEV range anxiety issues:
  - Plug-in hybrid vehicles (battery plus ICE),
  - Small number of highly visible public charging stations.
- Overnight charging facilitates using more wind energy.

Projections of charging load

- With few electric vehicles currently, effect on driving and electricity system is minimal:
  - Effects must be estimated from projections of available data,
- My student Mahdi Kefayati has used Seattle driving data and Texas electricity data to estimate average future charging scenarios:
  - Varying assumed penetrations of Plug-in Electric Vehicle (PEV) in the light vehicle fleet,
  - Nissan Leaf charging requirements, Level II EVSE.

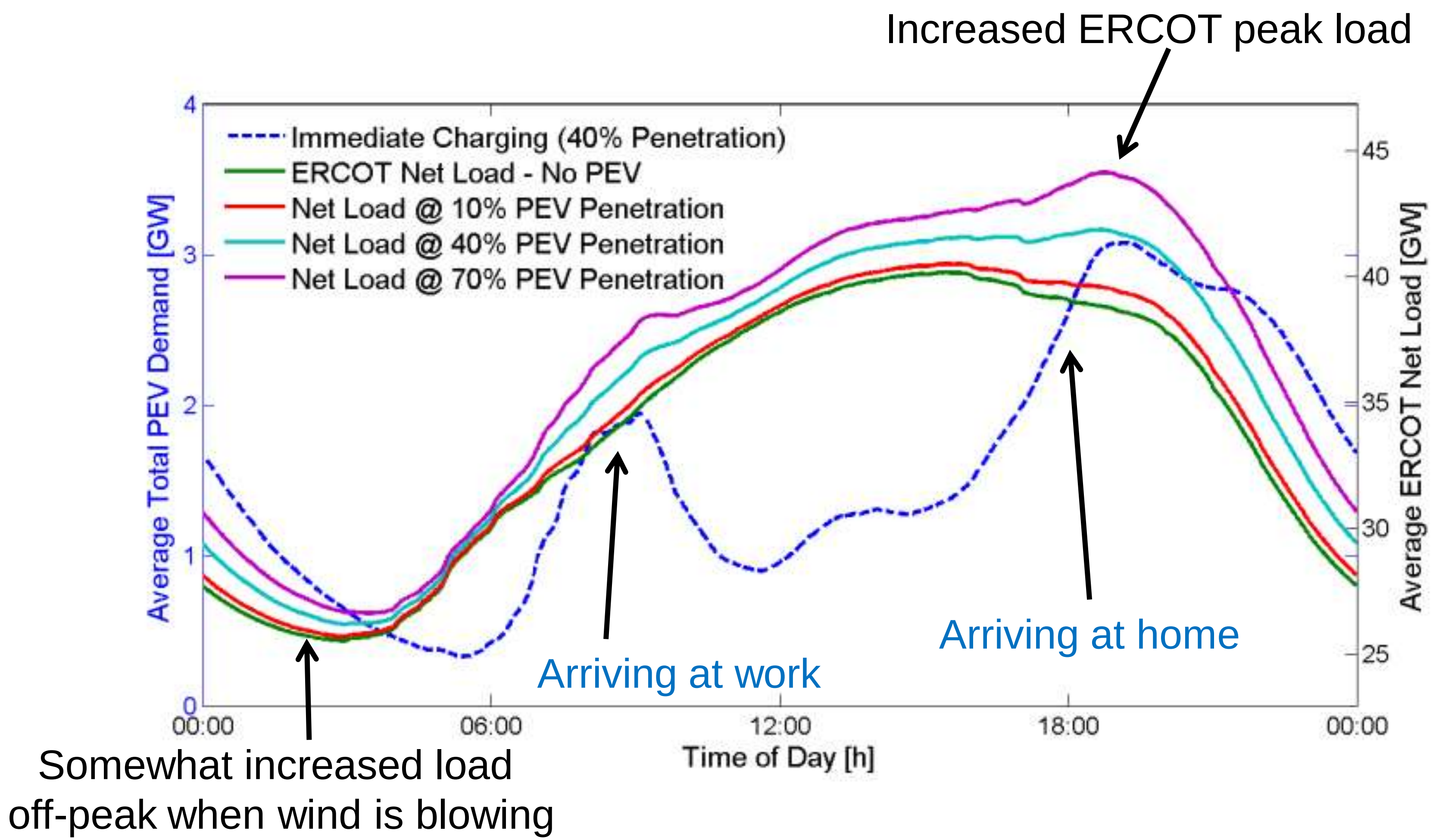
Projections of charging load

- Most of Texas is part of the Electric Reliability Council of Texas (ERCOT),
- Most Texas wind is generated within ERCOT.
- Net load = difference between load minus wind production:
  - Supplied by thermal generation system,
- Significant growth in on-peak net load would require more investment in generation, transmission, and distribution.

Projections of charging load

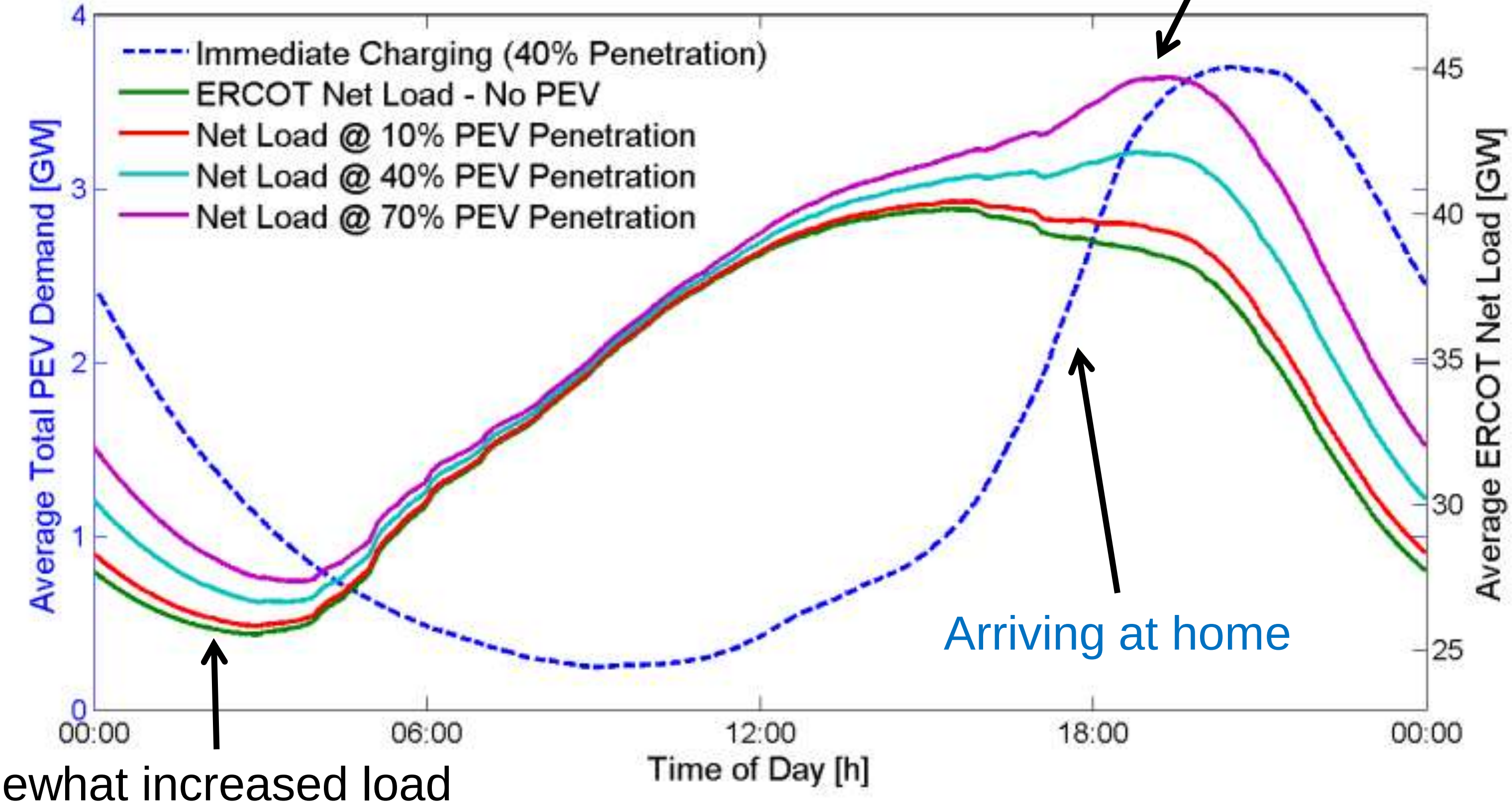
- Comparisons of timing and rate of charge:
  - Immediate: at maximum rate as soon as plugged in (like charging a cellphone),
  - Delayed (“grid friendly”): at maximum rate in the last hours before departure (available in some PEVs),
  - “Average rate” (Mahdi’s idea): at minimum rate necessary to charge between plug in and departure.
- Comparisons of availability of EVSEs:
  - Whenever stopped for more than three hours,
  - At home (primarily overnight) charging only.

Immediate Charging



Immediate Charging at Home

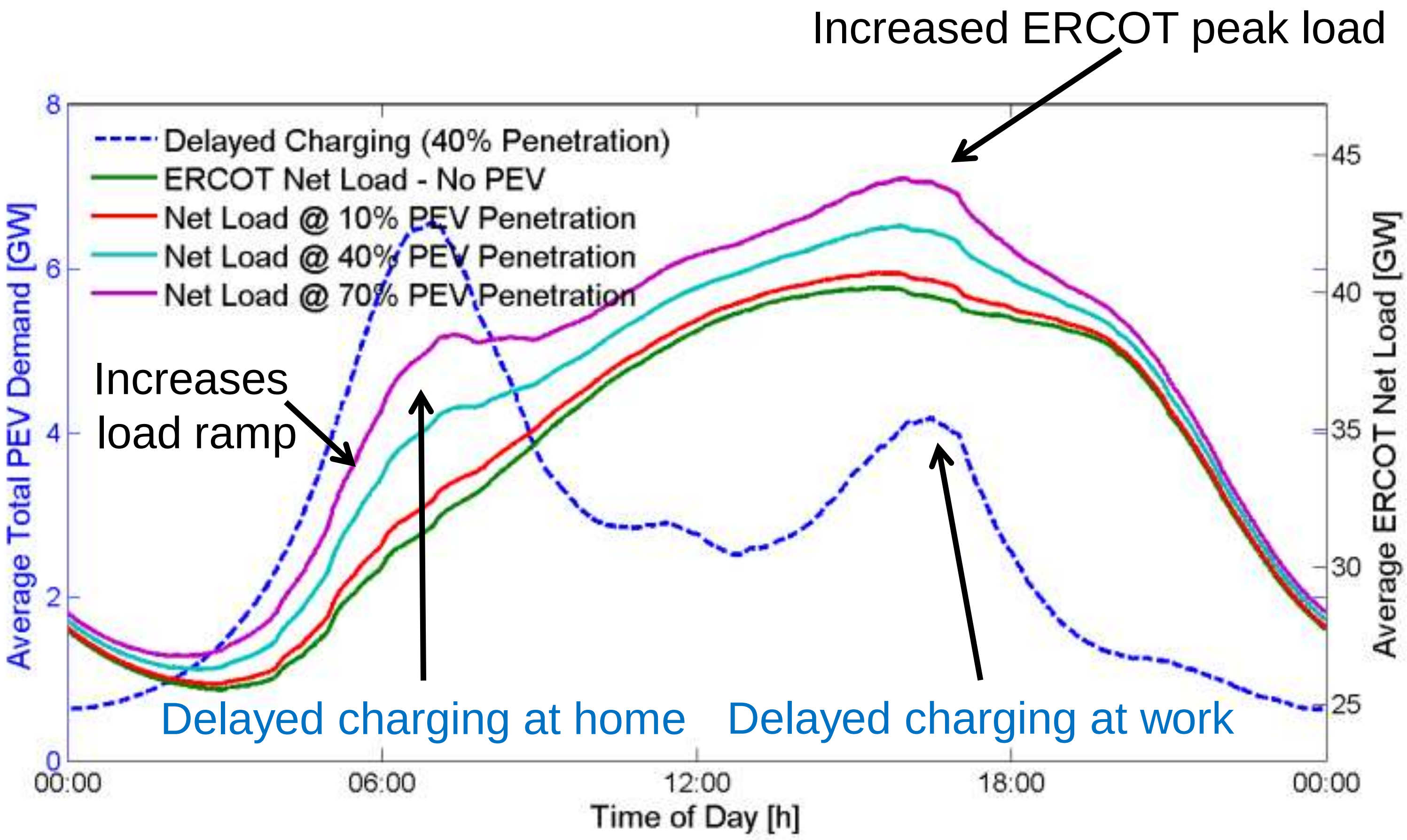
Increased ERCOT peak load



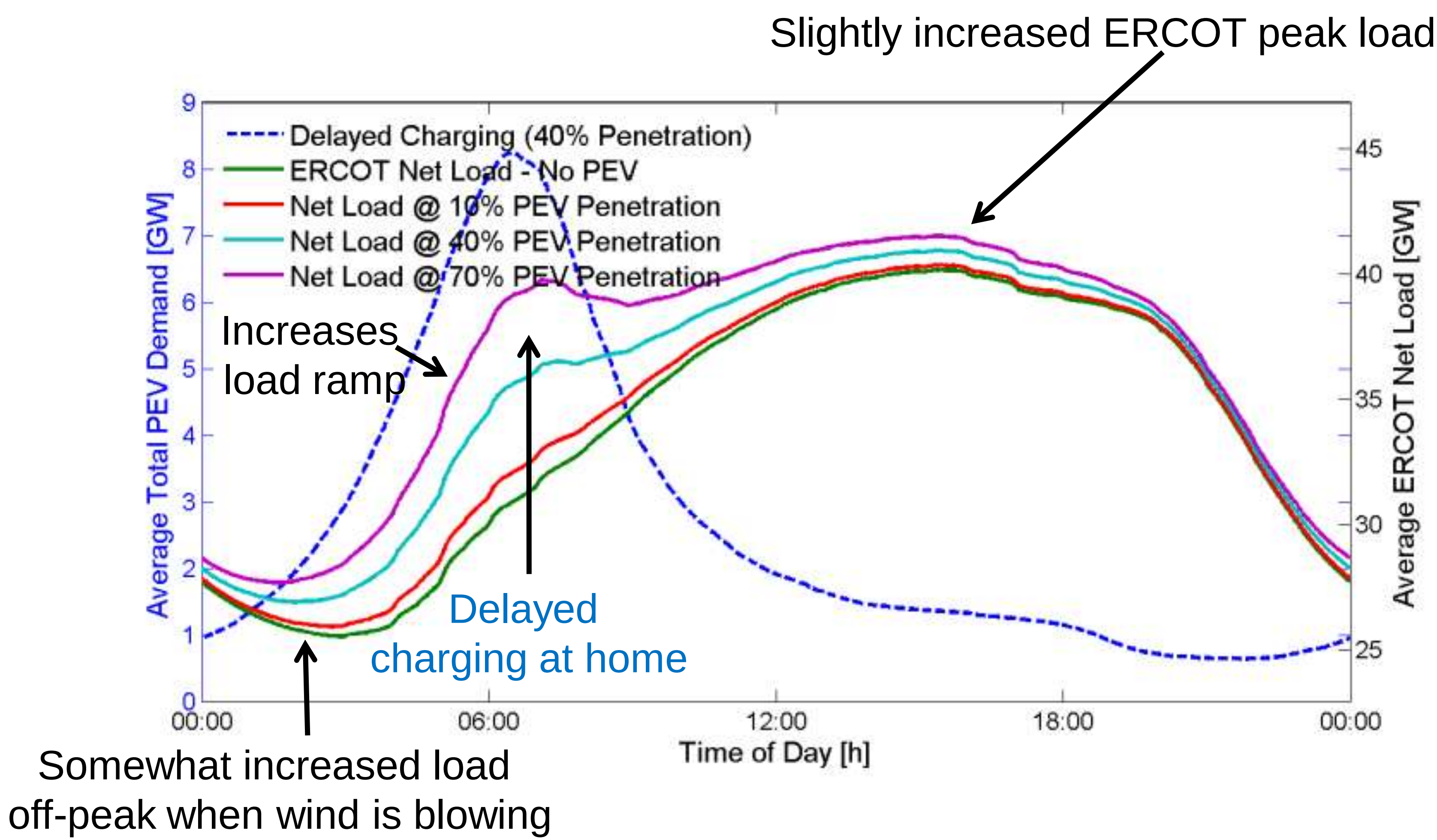
Arriving at home

Somewhat increased load off-peak when wind is blowing

Delayed Charging

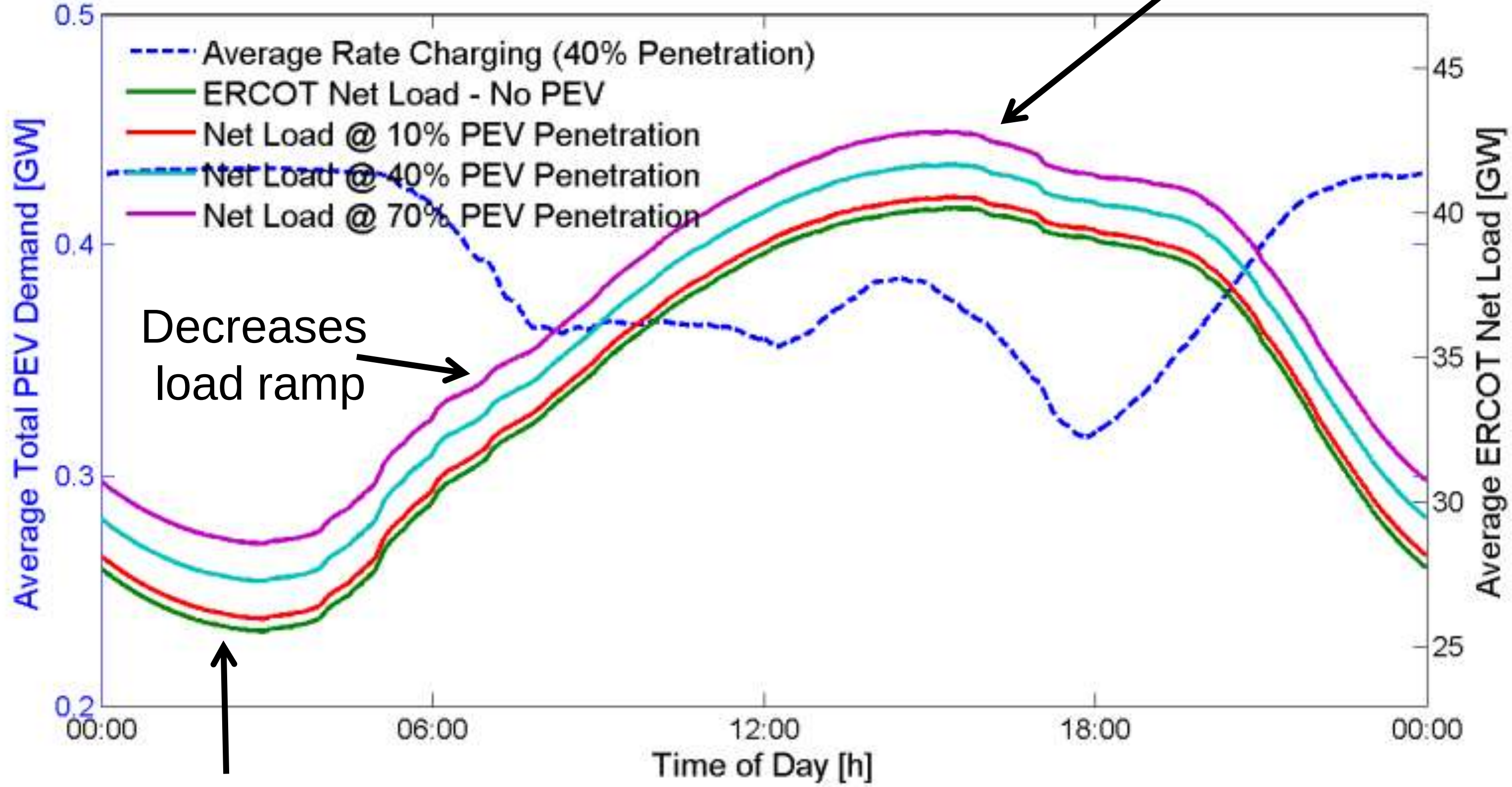


Delayed Charging at Home



Average Rate Charging

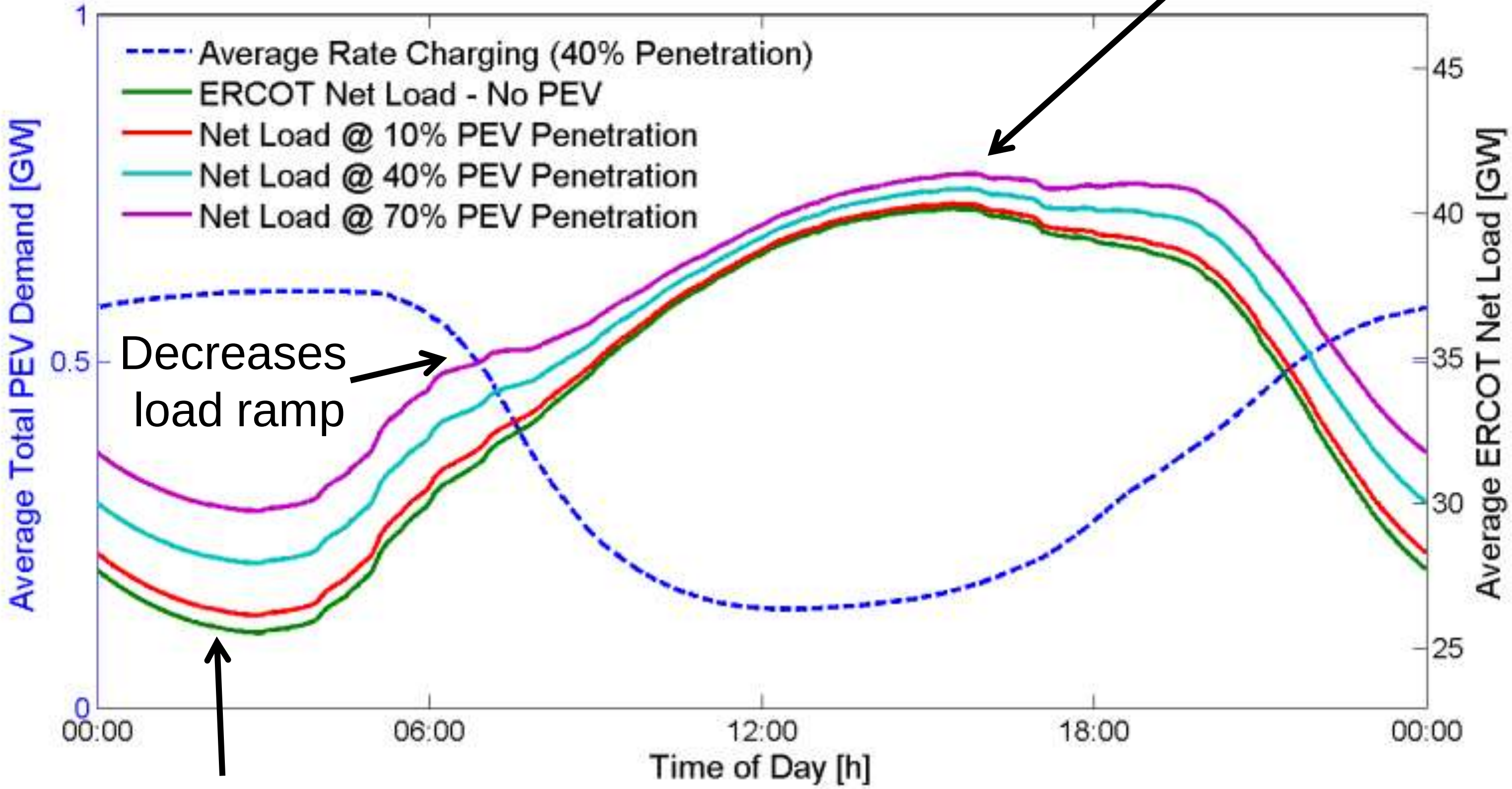
Increased ERCOT peak load



Increased load off-peak when wind is blowing

Average Rate Charging at Home

Slightly increased ERCOT peak load,
but flattens out overall peak



Increased load off-peak when wind is blowing

Paradigm shift of home charging

- Average rate charging at home:
  - Slow charging off-peak matches minimum of net load and allows *better utilization* of electric grid, including wind,
  - *Avoids* need for significant expansion of (public) *infrastructure*,
  - Not trying to reproduce paradigm of gas station filling.
- Energy *and power* are both keys to electrification of transport.

Conclusion

- Vehicle electrification has great potential benefits.
- Consideration of *power* requirements suggests a change in paradigm compared to gas station filling.
- Slow overnight charging of electric vehicles using average rate policy can improve utilization of infrastructure,
- Energy *and power* are the keys!