Introduction and Major Contributions

- Two methods are developed for the modeling of electric vehicles (EVs) as energy storage considering efficiency and user behavior.
- Proposed models can be used to explore methods of grid or emergency support after extreme weather events or outages.
- An example case study is provided for the utilization of a fleet of vehicles in a residential neighborhood to provide localized support.

Energy Storage Operation using Available EVs

- The temporal mismatch between renewably generated energy availability and peak electricity demand could lead to large periods of unmet demand due to the variability of weather-based resources.
- Areas with high renewable penetration benefit from the integration of accompany energy storage but suffer from high costs of implementation and the need for specialized systems.
- The contribution of energy storage can be modeled depending on the imbalance between renewable energy and load demand.

\[
P_{\text{min}}(t) = P_{\text{gen}}(t) - P_{\text{dem}}(t)\]

\[
E_{\text{ES}}(t) = \eta_{\text{up}} E_{\text{ES}}(t-1) + P_{\text{ES}}(t)\Delta t
\]

\[
P_{\text{ES}}(t) = \begin{cases} 
P_{\text{ES}0}/\eta_{\text{up}} & P_{\text{ES}} > 0 \\
\eta_{\text{up}} P_{\text{ES}} & P_{\text{ES}} \leq 0 
\end{cases}
\]

\[
E_{\text{EV}}(t) = \begin{cases} 
E_{\text{EV}} & t \leq t_a \\
E_{\text{EV}} \eta_{\text{disch}} & t_a < t < t_b 
\end{cases}
\]

- The aggregate energy storage model is a conventional approach of aggregate energy storage with a bulk efficiency loss and availability.
- The distributed model proposes any method of dispatch depending on travel behavior and considering individual charging power.

Dynamic Wireless Charging for Maximal EV Availability

- Dynamic wireless charging systems (DWCS) allow for charging and discharging of vehicles in-motion with electromagnetic coupling.
- Energy can be provided at full roadway speed with control by grid-side power electronics in response to roadway traffic behavior with efficiencies greater than 92% for high power (50-200kW).
- Widescale implementation could reduce battery capacity requirements or enable self-sustaining operation.
- New developments include the capability to transmit over a sizable airgap of 8 inches with high-frequency operation (80-90kHz).
- Experimental public roads are under development in several states (Utah, Indiana, Michigan) and countries (France, Italy, Germany).
- The capability to connect in-route allows for near continuous EV availability for local grid support or renewably supplied charging.

Energy Storage Modeling – Aggregate and Distributed

- Two methods are developed and explored for modeling electric vehicle energy storage at the residential-level:
  1. An aggregate model considering a collection of EVs as a cluster with a bulk efficiency loss and availability.
  2. A distributed model with EVs clustered depending on travel behavior and considering individual charging power.
- The aggregate energy storage model is a conventional approach and assumes approximately ideal V2X operation for dispatch.
- The method of distributed dispatch proposes any number of EVs with their own capacities, travel behavior, and reserved state of charge (SOC) with independent operation.
- Publicly available travel behavior can allow for the creation of large distributions sampled for individual EVs.
- The trade-off is between aggregate and distributed case considering overall cost of investment.

Case Study – V2X for IEEE Distribution Resiliency After Extreme Weather Event

- Two case studies were performed: one assuming extreme weather at peak load and another with a day-long outage.
- A residential neighborhood like the IEEE 123 bus test feeder with 1700 homes and an assumed 2000 cars.
- Residential load was derived from experimental smart meter profiles for 5000 homes from the SET project in Glasgow, KY.
- Electric vehicles were assumed to have 80kWh capacity with 11kW V2X charging capability at home and work.
- Parametric sweeps were implemented for reserved energy capacity for V2X support and electric vehicle availability.

Conclusions

- The results of the case study indicate the potential grid support from interconnected EVs with varying user willingness.
- Higher vehicle availability, like that supported by DWCS, can cover power/demand deficit at a lower energy capacity.
- Proposed models could be used for distribution planning studies including incentives for V2X capable chargers.
- Future work will include the development of metrics to compare between aggregate and distributed case considering overall cost of investment.

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