NSF - Transportation CPS - Position Statement

Towards a Cyber Physical Model for Smarter Transportation Infrastructure

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Over the last few years a strong push is occurring to reduce the use of hydrocarbons in transportation and power industries. This trend is supported by the latest advances in battery, power electronics and PV technology, along with government mandates on energy independence and resilience, as well as an increased emphasis on a "smarter infrastructure". It is also enabled by the introduction of electric vehicles (EVs) and their close relatives Plug-in Hybrid Electric Vehicles (PHEVs) by major car manufacturers that have drastically increased consumer choices. The inherent mobility of EV loads and stochastic nature of renewable resources makes the power supply and demand along a distribution feeder hard to predict, which can cause transformer and line overloading, as well as excessively low voltages along the feeder. At the same time the automotive industry is developing connected vehicle technologies that have the potential to improve safety and traffic flow, while the power industry is installing a sensor network in the form of phasor measurement units and smart meters that will provide high-fidelity power flow information in the distribution system.

We envision this very large, interconnected and distributed system consisting of vehicles, charging stations, power distribution network and requisite computing and communication infrastructure as an inherently "cyber physical" system. Our work aims to understand and optimize the interaction between the new stochastic power sources (in the form of renewables) and loads (in the form of electric vehicles) in the context of minimizing the infrastructure investments and optimizing the distribution network efficiency and resilience. Through intelligent design and dispatch of these resources the transmission network stability and reliability can be maintained and even improved without adding new transmission and generation capacity to the grid, and with minimal infrastructure investments in the form of energy storage systems, used to afford larger time scales in decision making.

Our work focuses on three aspects: First, we plan to develop large-scale, high-fidelity power distribution and transportation network models. Our approach is to integrate the vehicle drive pattern data with the roadway network information to obtain spatially-dependent energy requests. Our detailed vehicle models allow for precise quantification of the vehicle energy requirements and battery charge acceptance rates, while the network modeling approach defines the temporal and spatial coordinates. Similarly, complete feeder models introduce realistic transmission network constraints into the system simulation.

Second, we wish to devise a real time communications layer for coordinating and incentivizing vehicle owners and operators, in order to achieve the optimal use of the existing infrastructure. Precise temporal behavior of EVs can be highly stochastic and thus hard to predict and consequently employ standard demand response management strategies. Using advanced vehicle-to-vehicle (V2V) and vehicle to infrastructure (V2I) communication channels combined with load forecasting methodologies for estimating the grid state will allow for the development of novel distributed algorithms that optimize the use of the available power infrastructure, while maximizing the number of electric miles driven. The outcome of this effort would be a set of algorithms to dispatch the available power to the vehicle fleet, while quantifying the practical communication requirements for system implementation.

Third, we emphasize the placement of the recharging, renewable and storage infrastructure in order to support a pre-defined penetration of EVs and PHEVs. This work will build directly from the high fidelity models we develop, using real GPS or statistical data, where available, in conjunction with the distribution feeder models. Our optimization approaches look to minimize cost functions that consider the infrastructure cost, vehicle deviation from the shortest path to sustain the vehicle charge, while ensuring that the transmission grid operates efficiently and robustly. We consider conventional contact charging at various power levels, as well as the option of dynamic wireless charging as methods to replenish the vehicle battery. The outcome of this work would be a set of best practice blueprints for a number of case studies, outlining infrastructure cost, efficiency and utilization.

The strength of our approach and our team lies in fully acknowledging the cyber-physical nature of this system and modeling it, then solving it by combining techniques from the electrical, the control, the computing and the stochastic aspects, simultaneously.