The Role of lug-In Ele tri Vehi les with Renewable Resour es in Ele tri ity Systems

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Abstract

Two technology options, renewable electricity generation and vehicle electrification, are being promoted to

consumers and to the economy. For instance, a share of the United States' military expenditure is devoted to protecting oil supplies abroad. Lipman and Delucchi (2010) estimate that the military expenditures associated with securing oil supplies from the Persian Gulf add an average of $0.03 to $0.16/gallon to the price of gasoline. Sudden fuel supply disruptions can occur despite these efforts, causing price spikes and reducing economic output. The National Research Council (2010) estimates that the costs of oil supply disruptions have ranged between $1.16 and $15.01/barrel in the United States. Aside from the geopolitical risks for security of supply, fossil fuels resources are limited by the finite amount of hydrocarbons on Earth. Even as new fossil fuel reserves are discovered, they cannot always be economically extracted and exploited. The overall diminishing reserves increase fuel supply costs.

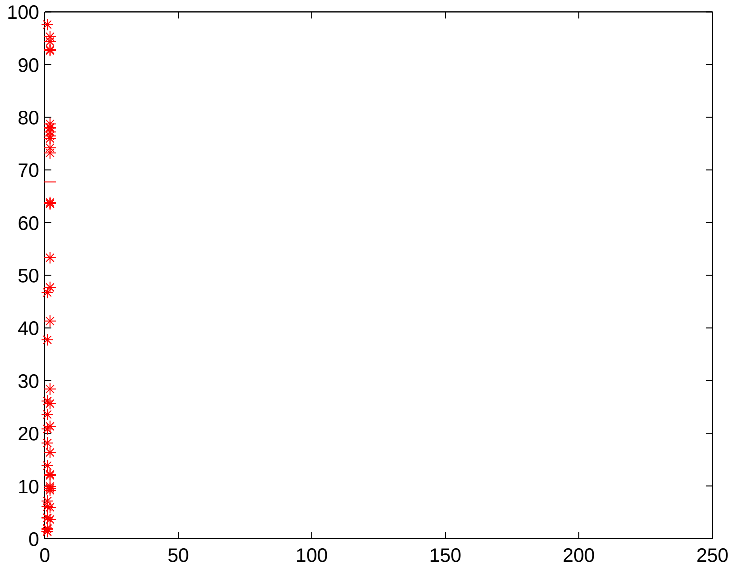
For these and other reasons, governments and other agencies around the world have begun searching for means to address this energy sustainability problem. Two technological solutions that have gained particular interest are renewable electricity sources and transportation electrification.

The EIA (2013) estimates that of the 553 EJ of world energy consumption in 2011, 39% was in the form of electricity. Moriarty and Honnery (2012) survey a number of studies estimating total global generation potential from renewable energy sources. These studies estimate between 246 EJ and 4842 EJ of generation potential. Renewable energy has the potential to improve energy sustainability in electric power systems and in the associated downstream activities and sectors. Moreover, transportation accounted for close to 20% of total world energy consumption in 2011, of which very little was electricity. Switching electricity generation to renewable sources can alleviate many of the problems associated with traditional generation feedstocks. Electrifying transportation can further leverage this switch in generation sources, since fossil fuels used directly in vehicles can be replaced with renewable electricity sources.

These technology solutions are not panacean, however. Both vehicle electrification and the use of renewable electricity sources raise serious technical, economic, and customer adoption issues.

Many renewable electricity sources that are commercially viable today have varying degrees of real-time supply uncertainty and variability. For instance, real-time wind speeds can be highly variable, due to complex interactions between weather fronts and other phenomena. These may be difficult to predict hours ahead, much less years ahead when capacity expansion decisions are made. Renewable resource variability and uncertainty raise a number of power system operations and planning challenges, since real-time electricity demand and supply must be in exact balance at all times to maintain power system stability and reliability.

as in the EV pilot conducted by the Tokyo Electric Power Company (TEPCO). TEPCO introduced a set of electric service vehicles, which were recharged overnight using ‘slow’ chargers at the TEPCO facility, for use over an 8 km $\times$ 15 km service area. They found that the EVs were used over a very small area around the facility and were typically returned to the station with a battery state of charge (SOC) much greater than 50%. A year later TEPCO installed a ‘fast’ charging station within the service area, which led to vastly greater use of the EVs over the entire service area. Interestingly, TEPCO found that the added charging proportional to efficiency, increases noticeably as the generator is more lightly loaded. In the long-run, a system that relies exclusively on supply-side flexibility must shift the generation mix toward more flexible units, which may have lower operating efficiencies than other technologies.



real-time availability of renewables. These characteristics of renewables affect power system operations and planning on a variety of timescales. To better understand these impacts, we first discuss the three main operational planning horizons that are pertinent to renewable integration. We then discuss how renewables affect these planning processes.

2.1. Power System Operations and Planning Processes

At one extreme, real-time active and reactive power demand and supply must be in constant balance to ensure that the system's frequency and voltage are within acceptable limits. These types of dynamic stability issues must be studied and managed on the milliseconds to seconds timescale.

The next level of operational planning includes unit commitment, economic dispatch, and optimal power flow analyses. Unit commitment, which may be done on an hour- to week-ahead basis, determines which generators must operate at each time step within the planning horizon to serve forecasted demand at hours to startup some generators,[4] the set of generators that is committed must have sufficient excess capacity and ramping capability to respond to unexpected reductions or increases in renewable availability. In some systems this flexibility is ensured by adjusting reserve requirements in the operational planning models, whereas others have introduced new reserve or flexibility products. For instance, Abdul-Rahman et al. (2012) discuss the introduction of a flexi-ramp constraint in the California ISO's operational planning process and Wang and Hobbs (2014) compare the operational benefits of this constraint to other renewable planning mechanisms. This constraint, which was originally only enforced in the real-time dispatch, ensures that the

historical reserve prices, showing that they are typically highest when the market is short. In addition to the value of reducing demand in short systems, PEVs could provide value as power sources as well. Their value as supply-side resources is discussed in greater detail in the following section.

3.3. Real-Time, Supply-Side and Storage Resource

If bidirectional power transmission is implemented between PEVs and value proposition of smart energy management by consumers. Individual consumers who have their own renewable energy generation units, such as solar panels in their homes, and a PEV, have all the more reason to use their smart meters to manage and optimize their consumption, generation, and storage capacity.

PEVs may be increasingly committed as power sources in energy markets when their sales penetration makes them available by millions. Until then, individual battery capacities of mid-sized PEVs, which range between around 20 kWh and 85 kWh, will not be significant enough to moderate renewable energy generation on the wholesale level. For PEV applications to be viable at the wholesale level, capacities of at least 1 MW to 2 MW would have to be traded in each V2G transaction, *i.e.*, roughly the equivalent of

4.2. Business Models

Business models describe the value proposition and the structure of relationships that enable an organization or a network of organizations to create and capture value around a new business opportunity (Zott and Amit (2010)). PEVs suffer from a lack of an attractive value proposition for buyers, as noted in Section 1, because of high upfront costs due to the battery component and the phenomenon of 'range anxiety' due to the combination of limited vehicle range and the scarcity of available charging infrastructure. Redefining the business model for PEVs by accounting for their valu

Functionality	Main Beneficiaries	Main Value	Sources of Service Provider(s)	Cost Distribution
Passive (Uni-				

suppliers to capitalize on the synergy with renewables have been briefly discussed to solve some of the challenges to PEV market growth.

5. Concluding Remarks

This article discusses two technology options, renewable electricity generation and the electrification of

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