Sustainable Transportation with Electric Vehicles

Fanxin Kong
University of Pennsylvania

Xue Liu
McGill University

the essence of knowledge
Boston — Delft

Foundations and Trends® in Electric Energy Systems

Published, sold and distributed by:
now Publishers Inc.
PO Box 1024
Hanover, MA 02339
United States
Tel. +1-781-985-4510
www.nowpublishers.com
sales@nowpublishers.com

Outside North America:
now Publishers Inc.
PO Box 179
2600 AD Delft
The Netherlands
Tel. +31-6-51115274

The preferred citation for this publication is

F. Kong and X. Liu. *Sustainable Transportation with Electric Vehicles*. Foundations and Trends® in Electric Energy Systems, vol. 2, no. 1, pp. 1–132, 2017.

This Foundations and Trends® issue was typeset in LaTeX using a class file designed by Neal Parikh. Printed on acid-free paper.

ISBN: 978-1-68083-388-1

Editorial Scope

Topics

Foundations and Trends® in Electric Energy Systems publishes survey and tutorial articles on the following topics::

- Advances in power dispatch
- Demand-side and grid scale data analytics
- Design and optimization of electric services
- Distributed control and optimization of distribution networks
- Distributed sensing for the grid
- Distribution systems
- Fault location and service restoration
- Integration of physics-based and data-driven modeling of future electric energy systems
- Integration of Power electronics, Networked FACTS
- Integration of renewable energy sources
- Interdependence of power system operations and planning and the electricity markets
- Microgrids: design, optimization, and stability
- Modern grid architecture
- Power system analysis and computing
- Power system dynamics
- Power system operation
- Power system planning
- Power system reliability
- Power system transients
- Security and privacy
- Stability and control for the whole multi-layer (granulated) network with new load models (to include storage, DR, EVs) and new generation
- System protection and control
- The new stability guidelines and control structures for supporting high penetration of renewables
- Uncertainty quantification for the grid
- System impacts of HVDC

Information for Librarians

Foundations and Trends® in Electric Energy Systems, 2017, Volume 2, 4 issues. ISSN paper version 2332-6557. ISSN online version 2332-6565. Also available as a combined paper and online subscription.

Foundations and Trends® in Electric Energy Systems
Vol. 2, No. 1 (2017) 1–132

DOI: 10.1561/3100000016

Sustainable Transportation with Electric Vehicles

Fanxin Kong
University of Pennsylvania

Xue Liu
McGill University

Contents

Abstract

Electric vehicles are gaining more and more popularity due to low oil dependency and low emission. Their deep penetration will significantly benefit the environment, but meanwhile will cause two crucial consequences. First, electric vehicles introduce heavy load impact into the power grid by shifting energy demand from gasoline to electricity. The surging load will compromise the grid's reliability and jeopardize its power supply quality. Second, charging stations become indispensable infrastructure to support large deployment of electric vehicles. The availability in public destinations comes with electric vehicles competing for both power supply and service points of charging stations. The competition degrades quality of service and thus can compromise the original intent of advocating electric vehicles.

There are many research efforts addressing either of the two consequences above. Different with them, we consider both and jointly study quality of service for electric vehicle users and reliability of the power grid. We review recent developments on this topic in this article. In Chapter 1, we introduce the ecosystem of electric vehicles and discuss motivations for managing charging load. This chapter further presents a systematic solution framework for smart electric vehicle charging. The following chapters then study each block of the framework. Specially, in Chapter 2, we investigate charging rate control, which handles how to allocate power supply to electric vehicles within a charging station. In Chapter 3, we address electric vehicle demand response, which is how to make electric vehicles follow the power supply of charging stations and the power grid. In Chapter 4, we study electric vehicle scheduling, which copes with how to schedule electric vehicles to multiple charging points within a charging station. In Chapter 5, we discuss charging demand balancing, which deals with how to balance electric vehicles among multiple charging stations.

In these chapters, we first present deployable algorithms and mechanisms that are designed for each framework blocks. Then, we evaluate the proposed approaches by two complementary ways. One way is leveraging theoretical analysis to demonstrate their performance guarantees, while the other is using extensive simulations based on realistic

data traces and simulation tools. We also review studies that align with the corresponding framework blocks and consider additional dimensions and/or different optimization goals. Finally, in Chapter 6, we conclude the article with summaries of main ideas discussed in the previous chapters.

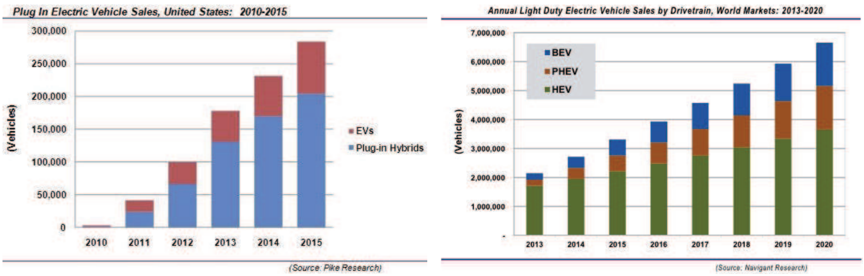
F. Kong and X. Liu. *Sustainable Transportation with Electric Vehicles*. Foundations and Trends® in Electric Energy Systems, vol. 2, no. 1, pp. 1–132, 2017.
DOI: 10.1561/3100000016.

1

Introduction and Overview

The transportation sector is by far the largest oil consumer and thus a prime contributor to air pollution. For example, the sector accounts for about 23% of the global GHG emissions in 2014 [1]. The growing concerns over environmental impacts and oil scarcity have boosted the need to electrify the transportation sector and spurred efforts to accelerate the adoption of electric vehicles (EVs). As shown by Fig. 1.1(a), the yearly EV sales for U.S. have grown more than 6 times from 2011 to 2015, and as shown by Fig. 1.1(b), the worldwide yearly sales would be over 6 million by 2020. Further, the number of EVs in the globe would be over 35 million by 2022 [2].

The popularity of EVs will significantly benefit the environment and alleviate energy crisis, but meanwhile will cause heavy load impact to the power grid due to shifting energy demand from gasoline to electricity. The potential impact includes compromising the grid's reliability and jeopardizing its power quality. For example, uncoordinated EV charging can increase the peak load and energy losses and overload distribution lines and transformers [3, 4, 5, 6]. Overloading can overheat the transformers, and accelerate their degradation, and eventually cause premature failure to them. This impact would be even severer



(a) U.S. EV sales 2010-2015 (b) World-wide EV sales 2013-2020

Figure 1.1: Market research about EV sales.

with some eco-friendly areas such as neighbourhoods with higher penetration of EVs.

Recently, various charging facilities have been deployed such as charging points in residential areas and working places [3, 7, 8, 9, 10, 11, 12]. Among them, charging stations have become indispensable infrastructure to support the deep integration of electric vehicles [10, 11, 12, 13, 14]. Meanwhile, one crucial consequence following their public availability is that EVs will compete for charging resources such as power supply and service points of these charging stations. This competition can much degrade the quality of service if there is no coordination performed among EV users when making decisions on choosing charging stations. For example, some charging stations may be overloaded with long waiting queues of charging demand (and thus long waiting time for EVs) while others barely have EVs to serve. Some EVs that have a tight schedule may be allocated with lower power supply than EVs with adequate spare time for charging.

There are two different methods to accommodate the large-scale EV charging load. The first method is to make the required investment to upgrade the power grid and build more charging facilities. The second method is to exploit the elasticity of charging load and existing communication networks to coordinate and control EV charging, i.e., to enable smart EV charging. This method postpones upgrading or building new charging infrastructure and thus substantially reduces the required reinforcement investment [15, 16]. This article focuses on the latter method and studies smart EV charging. In the following, we first present an overview for electric vehicles and charging infrastructure, and then reveal emerging challenges and propose a systematic solution framework for smart EV charging.

1.1 Electric Vehicle Overview

Although EVs were first introduced many decades ago, their resurgence and actual popularity start recently due to technological developments and the environmental impact of petroleum-based transportation [17]. Electric vehicles use electric motors for propulsion and can be powered by electricity from on-board batteries. In contrast, conventional vehicles use internal combustion engines for propulsion and usually depend on non-renewable fossil fuels. These two kinds of vehicles are different in that the electricity EVs consume can be generated from a wide range of energy sources, including fossil fuels and renewable sources such as solar power and wind power or the combinations of those sources. EVs, if sourcing from renewable, thus come with lower carbon footprint and other emissions than conventional vehicles.

This article confines to studying plug-in electric vehicles, which can be recharged from any external source of electricity, such as the power grid and local renewable generation. Plug-in EVs can be further classified into two different types: all-electric or battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). BEVs only use electric motors for propulsion instead of internal combustion engines. They have no fuel tank and derive all power from rechargeable batteries on-board. Examples of BEVs include Nissan Leaf, Ford Focus Electric, Tesla Model S, BMW i3, and BYD Qin EV300. Fig. 1.2(a) shows Nissan Leaf 2017. PHEVs share the characteristics of both conventional vehicles and BEVs, and thus have both electric motors and internal combustion engines. They can derive power both from on-board batteries that can be recharged by plugging into external sources, and from combusting fossil fuel from fuel tanks. Examples of PHEVs include Chevrolet Volt, BYD F3DM, BMW i8, and Toyota Prius. Fig. 1.2(b) shows Chevrolet Volt 2017.

(a) Nissan Leaf 2017

(b) Chevrolet Volt 2017

Figure 1.2: Examples of BEV and PHEV.

Most plug-in EVs of this generation use lithium-ion (li-ion) batteries. Compared to most other rechargeable batteries, li-ion batteries have advantages such as higher energy density, higher power density, and long life span. For example, Nissan Leaf has 30 kWh battery pack with 172 km on a full battery charge, while the latest Tesla Model S is equipped with 100 kWh battery pack, which can allow a driving range as long as 539 km. Battery life span is defined as the number of full charge-discharge cycles before significant capacity loss. Li-ion batteries degrade, in terms of capacity, energy efficiency, as the number of cycles increases. To maintain a long life span, li-ion batteries should not operate with frequent mode switching, i.e., switching between charging and discharging. One disadvantage is that li-ion batteries can pose safety issues since they contain flammable electrolytes. For example, it would be very risky to charge EV batteries with a power supply larger than the allowed maximum charging rate. In order to operate safely and efficiently, li-ion batteries should be used within safe temperature and certain power ranges.

1.2 Charging Infrastructure Overview

Charging stations or charging points are a fundamental element in charging infrastructure that supplies electricity for the recharging of EVs. The charging infrastructure usually exists in three different contexts. The first is residential charging stations, where an EV owner plugs in when he or she at home, and the EV usually charges overnight

Table 1.1: Charging Standard Specification [23].

Charging Level	Voltage [V]	Max. Current [A]	Max. Power [kW]
AC Level 1	120	12	1.44
AC Level 2	208-240	48	11.5
AC Level 3	208-240	400	96
DC Charging	208-600	400	240

[3, 18]. The second context is park-and-charge, i.e., charging while parked, where a parking lot is equipped with charging function and EVs can receive recharging while parked [19, 20]. This scenario encourages EV users to take advantage of nearby facilities, such as parking stations including parking at malls, working places and airports. The third is publicly available fast charging stations, which usually can provide an individual charging rate larger than 40 kw and takes dozens of minutes to deliver tens of miles [5]. This article mainly studies charging stations falling into the latter two contexts, i.e., publicly available charging stations.

As EV ownership is expanding, there is a growing need for charging stations available in public destinations. As of the end of 2015, the number of public charging points deployed in the globe reached around $190k$, up from $110k$ in 2014 and about $50k$ in 2013 [21]. As of May 2017, around $16k$ electric stations and about $43k$ charging points are available to the public in North America [22]. These charging stations leverage multiple sensors such as current sensors to provide better safety and reliability than residential charging points. These sensors can monitor the power consumed and EVs can be automatically connected or disconnected according to the power demand status. With this capability, public stations can protect the charger and EVs from overheating and thus potential damages. Further, public charging stations are usually capable of charging EVs with higher charging rate than residential charging points, because different charging standards and techniques are applied to the two different contexts.

Charging standards used in North American mainly follow the SAE International standard SAE J1772, where four standards are developed [23]. Table 1.1 shows the specification for the four charging standards. AC level 1 has the lowest power capacity and is mainly used in residential charging points, or other application scenarios that EV users have plenty of time for recharging their vehicles. By contrast, the other three standards have much higher power capacity and are used by most public charging stations, or other application scenarios that there are high expectations on charging rate and charging time. The fast charging capability of AC level 3 and DC charging can significantly shorten the charging time of EVs. For example, charging time for 100 km is about $20 - 30$ minutes with AC level 3 and it is about 10 minutes with DC charging.

Fast charging stations, especially those enabled with AC level 3 and DC charging, introduce high power load on the power grid. There are two ways that can mitigate this load impact. One way is to schedule and coordinate EV charging according to the load status of the power grid, e.g., charging EVs when the power grid has reduced load or reduced electricity cost. One enabler to coordinating EV charging is that EVs, charging stations and the power grid can communicate with each other. The other way is to locally install power generation such as solar power to loose the need for the power grid, which thus alleviates the load impact caused by EV charging. Another advantage here is that EVs can source from the power grid at opportune time to reduce their charging cost, such as at off-peak time or when the electricity price is high. In this article, we study both methods as well as the combination of these two methods.

1.3 Electric Vehicle Charging Overview

The increasing integration of electric vehicles has motivated many research efforts from both industry and academia. These efforts can be partitioned into two important groups, which respectively address the two crucial consequences mentioned above. The first group centers around the power grid oriented consequence, which is the associated heavy load impact that can compromise the stability and reliability of the power grid. The second group focuses on the EV user oriented consequence, which is the quality of service degradation caused by EVs' competition on charging resources including charging points and the power supply.

Power Grid Oriented EV Charging. Studies falling into this group address how to mitigate the potential grid impact associated with large-scale EV charging. Unbalance between charging demand and power supply will occur if the interaction between EVs and the power grid is uncontrolled or uncoordinated. This fact is revealed in [24], which shows that there is a positive dependence between charging load impact and the penetration levels of EVs. Uncoordinated loads can cause a series of issues such as power loss, low energy efficiency, frequency deviation, and voltage deviation, which in turn jeopardize the stability and reliability of the power grid. These issues are investigated by two major research threads.

The first thread is load flattening and example works include [4, 25, 26, 27, 28, 29, 30]. In general, these works alleviate the unbalance between charging demand and power supply through shifting charging demand to the power valley of the power grid, i.e., valley filling. Flattening power load is further demonstrated to be effective to improve energy efficiency and power loss of the power grid [6]. The second thread is frequency regulation and example studies include [31, 32, 33, 34, 35]. A gap between power supply and demand on the power grid causes the grid frequency to deviate from its nominal value, and the goal of frequency regulation is to reduce this gap. EVs are capable of making rapid response to frequency changes, and thus they are regarded as suitable for providing frequency regulation service. However, conventionally, power generators that are capable of providing MW-scale power are utilized for frequency regulation. To meet this power capacity threshold, these existing works investigate the aggregated power by a large number of vehicles and regard these EVs as a whole to provide frequency regulation.

The above works focus on addressing the power grid impact. This confined focus can cause degradation to quality of service to EV users, i.e., blindly following requirements from the power grid may not result in beneficial results for EV users. For example, a number of EVs may have to charge at rather low rates to reduce power load on the grid, which will compromise user satisfaction. Different with these existing works, this article considers both the power grid and EV users and jointly studies the stability and reliability of the former and quality of service for the latter.

EV User Oriented EV Charging. Works belonging to this group study how to well handle the competition on charging resources in order to improve EV user satisfaction or quality of service. EV user satisfaction depends on key aspects such as charging cost, charging time, charging rate, and travel distance/time to charging points. There are two major research threads that present charging schemes to benefit EV users in terms of the above aspects.

The first thread is opportune charging and/or discharging and example works include [36, 37, 38, 39, 40, 41]. In general, these works charge and/or discharge vehicles at some opportune time. For example, charging EVs when the electricity price is low results in reduced charging cost, and charging EVs when the charging rate is high will reduce charging time. The second thread is EV routing and examples studies include [42, 43, 44]. As to the routing problem for fuel-based vehicles, it usually needs to consider only two factors: fuel price and travel distance/time to gas stations. As to EV routing, besides charging price and travel distance/time to charging stations, it needs to consider another key factor, which is queueing time. The existence of queueing for EV charging is mainly because of two reasons: EV charging takes much longer time compared to gas fueling and there is a limited number of charging points. Thus, there is a much higher opportunity for EVs to queue and wait for the availability of charging points, and further their waiting time is usually much longer. To reduce the queueing time and improve quality of service, it should distribute EVs to charging stations as evenly as possible. However, to follow routes with reduced queueing time may conflict with the other goals such as reducing charging cost and travel distance/time to stations.

These existing works only discuss one or two of the mentioned aspects related to user satisfaction. By contrast, we present a holistic framework that studies multiple aspects including not only all the men-

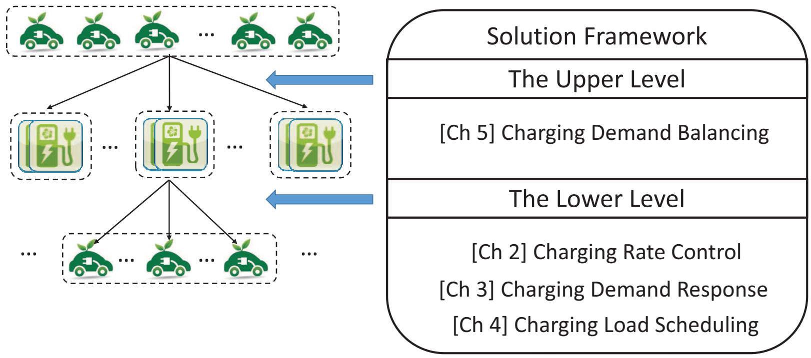


Figure 1.3: A figure illustrating the application scenario and a block diagram showing the proposed systematic solution framework.

tioned aspects but also new aspects such as the level of users' urgency and user behavior's uncertainty. Further, many works of the first thread consider a direct interaction between the power grid and charging stations, and all works of the second thread only consider the interaction between charging stations and EV users. By contrast, this article discusses a hierarchical interaction among the power grid, charging stations, and EV users.

1.4 A Systematic Solution Framework

This article considers an application scenario, as illustrated in Fig. 1.3, where multiple charging stations are publicly available in an urban area and many electric vehicles demands charging service from these charging stations. For this application scenario, we propose a systematic solution framework that employs a hierarchical operational structure. There are two levels in the framework.

The lower level determines how to allocate power supply to vehicles plugged in within a charging station. For this level, we discuss three different cases according to the operation mode of the power grid and the configuration of charging facilities. The first two cases both investigate charging facilities that are able to change power rates continuously. The difference between them is that one case, called charging rate control, focuses on the normal operation of the power grid, while the other case, called charging demand response, confines to the demand response period of the power grid. The two cases leverage time-driven methods due to the continuity of charging rate regulation. By contrast, the third case, called charging load scheduling, handles charging facilities with fixed charging rates. This case adopts event-driven methods to schedule vehicles to multiple charging points within a charging station.

The upper level decides how to balance vehicles that are demanding charging service among multiple charging stations, which is called charging demand balancing. The decision is made according to several key factors including charging demand of each individual vehicle, travel distances to charging stations, and detour distances to destinations, charging prices of charging stations, and uncertainty of EV user behavior. We propose several efficient and effective decision-making algorithms for this level.

1.5 Road Map

Fig. 1.3 depicts the road map of this article. Chapter 2 to Chapter 4 focus on the lower level and study charging rate control, charging demand response, and charging load scheduling respectively. Chapter 5 confines to the upper level and discusses charging demand balancing. In these chapters, we first design deployable algorithms and mechanisms and then evaluate the proposed approaches through two complementary methods. One method is to use theoretical analysis to demonstrate their performance guarantees, while the other method is to leverage extensive simulations based on realistic data traces and simulation tools. We also review existing studies that align with the problems studied in each chapter and further consider additional dimensions and/or different optimization goals. Finally, in Chapter 6, we conclude the article with summaries of main ideas discussed in the previous chapters.

References

[1] International Energy Agency. Co2 emissions from fuel combustion highlights 2016. `http://www.iea.org/`. [Online accessed Feb., 2017].

[2] Liansheng Liu, Fanxin Kong, Xue Liu, Yu Peng, and Qinglong Wang. A review on electric vehicles interacting with renewable energy in smart grid. *Renewable and Sustainable Energy Reviews*, 2015.

[3] Kristien Clement-Nyns, Edwin Haesen, and Johan Driesen. The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. *IEEE Transactions on Power Systems*, 2010.

[4] João A Peças Lopes, Filipe Joel Soares, and Pedro M Rocha Almeida. Integration of electric vehicles in the electric power system. *Proceedings of the IEEE*, 2011.

[5] Fanxin Kong, Xue Liu, Zhonghao Sun, and Qinglong Wang. Smart rate control and demand balancing for electric vehicle charging. In *ICCPS*. IEEE, 2016.

[6] Qinglong Wang, Xue Liu, Jian Du, and Fanxin Kong. Smart charging for electric vehicles: A survey from the algorithmic perspective. *IEEE Communications Surveys & Tutorials*, 2016.

[7] Jing Huang, Vijay Gupta, and Yih-Fang Huang. Scheduling algorithms for phev charging in shared parking lots. In *ACC*. IEEE, 2012.

[8] ChargePoint. We are chargepoint. `http://www.chargepoint.com`. [Online accessed June, 2015].

[9] Omid Ardakanian, Catherine Rosenberg, and Srinivasan Keshav. Distributed control of electric vehicle charging. In *e-Energy*. ACM, 2013.

[10] Shiyao Chen, Yuting Ji, and Lang Tong. Large scale charging of electric vehicles. In *PES General Meeting*. IEEE, 2012.

[11] Wikipedia. Park & Charge. `http://en.wikipedia.org/wiki/Park_%26_Charge`. [Online accessed Apr., 2015].

[12] Julian Timpner and Lars Wolf. Design and evaluation of charging station scheduling strategies for electric vehicles. *IEEE Transactions on Intelligent Transportation Systems*, 2014.

[13] Zhipeng Liu, Fushuan Wen, and Gerard Ledwich. Optimal planning of electric-vehicle charging stations in distribution systems. *IEEE Transactions on Power Delivery*, 2013.

[14] Florian Hausler, Emanuele Crisostomi, Arieh Schlote, Ilja Radusch, and Robert Shorten. Stochastic park-and-charge balancing for fully electric and plug-in hybrid vehicles. *IEEE Transactions on Intelligent Transportation Systems*, 2014.

[15] Robert C Green, Lingfeng Wang, and Mansoor Alam. The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook. *Renewable and sustainable energy reviews*, 2011.

[16] Luis Pieltain Fernandez, Tomás Gomez San Roman, Rafael Cossent, Carlos Mateo Domingo, and Pablo Frias. Assessment of the impact of plug-in electric vehicles on distribution networks. *IEEE Transactions on Power Systems*, 2011.

[17] Ulrich Eberle and Rittmar Von Helmolt. Sustainable transportation based on electric vehicle concepts: a brief overview. *Energy & Environmental Science*, 2010.

[18] Qiuming Gong, Shawn Midlam-Mohler, Vincenzo Marano, and Giorgio Rizzoni. Study of pev charging on residential distribution transformer life. *IEEE Transactions on Smart Grid*, 3(1):404–412, 2012.

[19] Qiao Xiang, Fanxin Kong, Xi Chen, Linghe Kong, Xue Liu, and Lei Rao. Auc2charge: An online auction framework for electric vehicle park-and-charge. In *e-Energy*. ACM, 2015.

[20] Fanxin Kong, Qiao Xiang, Linghe Kong, and Xue Liu. On-line event-driven scheduling for electric vehicle charging via park-and-charge. In *RTSS*. IEEE, 2016.

[21] International Energy Agency. Global ev outlook 2016: Beyond one million electric cars. `https://www.iea.org/`. [Online accessed May, 2017].

[22] U.S. Department of Energy. Electric vehicle charging station locations. `http://www.afdc.energy.gov/`. [Online accessed May, 2017].

[23] SAE EV Charging Systems Committee . Sae surface vehicle recommended practice j1772, sae electric vehicle conductive charge coupler. http://www.arb.ca.gov/. [Online accessed May, 2017].

[24] Jason Taylor, Arindam Maitra, Mark Alexander, Daniel Brooks, and Mark Duvall. Evaluation of the impact of plug-in electric vehicle loading on distribution system operations. In *IEEE Power & Energy Society General Meeting (PES)*. IEEE, 2009.

[25] Lingwen Gan, Ufuk Topcu, and S Low. Optimal decentralized protocol for electric vehicle charging. *IEEE Transactions on Power Systems*, 2013.

[26] Lingwen Gan, Ufuk Topcu, and Steven H Low. Stochastic distributed protocol for electric vehicle charging with discrete charging rate. In *PES General Meeting*. IEEE, 2012.

[27] Lingwen Gan, Adam Wierman, Ufuk Topcu, Niangjun Chen, and Steven H Low. Real-time deferrable load control: handling the uncertainties of renewable generation. In *e-Energy*. ACM, 2013.

[28] Zhongjing Ma, Duncan Callaway, and Ian Hiskens. Decentralized charging control for large populations of plug-in electric vehicles. In *CDC*. IEEE, 2010.

[29] Eric Sortomme, Mohammad M Hindi, S.D. James MacPherson, and S.S. Venkata. Coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses. *IEEE transactions on smart grid*, 2011.

[30] Sara Deilami, Amir S Masoum, Paul S Moses, and Mohammad AS Masoum. Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile. *IEEE Transactions on Smart Grid*, 2011.

[31] Sekyung Han, Soohee Han, and Kaoru Sezaki. Estimation of achievable power capacity from plug-in electric vehicles for v2g frequency regulation: Case studies for market participation. *IEEE Transactions on Smart Grid*, 2011.

[32] Sekyung Han, Soohee Han, and Kaoru Sezaki. Development of an optimal vehicle-to-grid aggregator for frequency regulation. *IEEE Transactions on smart grid*, 2010.

[33] Willett Kempton and Jasna Tomić. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. *Journal of power sources*, 2005.

[34] Chenye Wu, Hamed Mohsenian-Rad, Jianwei Huang, and Juri Jatskevich. Pev-based combined frequency and voltage regulation for smart grid. In *IEEE PES Innovative Smart Grid Technologies (ISGT)*. IEEE, 2012.

[35] Hongming Yang, CY Chung, and Junhua Zhao. Application of plug-in electric vehicles to frequency regulation based on distributed signal acquisition via limited communication. *IEEE Transactions on Power Systems*, 2013.

[36] Yifeng He, Bala Venkatesh, and Ling Guan. Optimal scheduling for charging and discharging of electric vehicles. *IEEE Transactions on Smart Grid*, 2012.

[37] Casey Quinn, Daniel Zimmerle, and Thomas H Bradley. An evaluation of state-of-charge limitations and actuation signal energy content on plug-in hybrid electric vehicle, vehicle-to-grid reliability, and economics. *IEEE Transactions on Smart Grid*, 2012.

[38] MF Shaaban, Muhammad Ismail, EF El-Saadany, and Weihua Zhuang. Real-time pev charging/discharging coordination in smart distribution systems. *IEEE Transactions on Smart Grid*, 2014.

[39] Zizhan Zheng and Ness B Shroff. Online welfare maximization for electric vehicle charging with electricity cost. In *e-Energy*. ACM, 2014.

[40] Niklas Rotering and Marija Ilic. Optimal charge control of plug-in hybrid electric vehicles in deregulated electricity markets. *IEEE Transactions on Power Systems*, 2011.

[41] Jonathan Donadee and Marija D Ilie. Stochastic optimization of grid to vehicle frequency regulation capacity bids. *IEEE Transactions on Smart Grid*, 2014.

[42] Tarek Abdelzaher and etc. Green gps : A participatory sensing fuel-efficient maps application. `http://green-way.cs.illinois.edu/`. [Online accessed June, 2015].

[43] Moritz Baum, Julian Dibbelt, Thomas Pajor, and Dorothea Wagner. Energy-optimal routes for electric vehicles. In *SIGSPATIAL*. ACM, 2013.

[44] Martin Sachenbacher, Martin Leucker, Andreas Artmeier, and Julian Haselmayr. Efficient energy-optimal routing for electric vehicles. In *AAAI*, 2011.

[45] Albert G Boulanger, Andrew C Chu, Suzanne Maxx, and David L Waltz. Vehicle electrification: status and issues. *Proceedings of the IEEE*, 2011.

[46] Navid Rahbari-Asr and Mo-Yuen Chow. Cooperative distributed demand management for community charging of phev/pevs based on kkt conditions and consensus networks. *IEEE Transactions on Industrial Informatics*, 2014.

[47] Kevin Mets, Tom Verschueren, Wouter Haerick, Chris Develder, and Filip De Turck. Optimizing smart energy control strategies for plug-in hybrid electric vehicle charging. In *IEEE/IFIP Network Operations and Management Symposium Workshops (NOMS Wksps)*. IEEE, 2010.

[48] Amir S Masoum, Sara Deilami, Ahmed Abu-Siada, and Mohammad AS Masoum. Fuzzy approach for online coordination of plug-in electric vehicle charging in smart grid. *IEEE Transactions on Sustainable Energy*, 2015.

[49] Chenye Wu, Hamed Mohsenian-Rad, and Jianwei Huang. Vehicle-to-aggregator interaction game. *IEEE Transactions on Smart Grid*, 2012.

[50] George R Parsons, Michael K Hidrue, Willett Kempton, and Meryl P Gardner. Willingness to pay for vehicle-to-grid (v2g) electric vehicles and their contract terms. *Energy Economics*, 2014.

[51] Emil B Iversen, Juan M Morales, and Henrik Madsen. Optimal charging of an electric vehicle using a markov decision process. *Applied Energy*, 2014.

[52] Omid Ardakanian, Srinivasan Keshav, and Catherine Rosenberg. Real-time distributed control for smart electric vehicle chargers: From a static to a dynamic study. *IEEE Transactions on Smart Grid*, 2014.

[53] Lijun Chen, Na Li, SH Low, and JC Doyle. Two market models for demand response in power networks. In *SmartGridComm*. IEEE, 2010.

[54] Lazaros Gkatzikis, Iordanis Koutsopoulos, and Theodoros Salonidis. The role of aggregators in smart grid demand response markets. *IEEE Journal on Selected Areas in Communications*, 2013.

[55] Zhenhua Liu, Iris Liu, Steven Low, and Adam Wierman. Pricing data center demand response. In *SIGMETRICS*. ACM, 2014.

[56] TimberRock Energy Solutions. `http://timberrockes.com/`. [Online accessed Feb., 2015].

[57] UGE (Urban Green Energy). `http://www.urbangreenenergy.com/`. [Online accessed Feb., 2015].

[58] Wikipedia. Charging station. `https://en.wikipedia.org/wiki/Charging_station`. [Online accessed Feb., 2015].

[59] Fanxin Kong and Xue Liu. Distributed deadline and renewable aware electric vehicle demand response in the smart grid. In *RTSS*. IEEE, 2015.

[60] Jian Yao, Shmuel S Oren, and Ilan Adler. Two-settlement electricity markets with price caps and cournot generation firms. *European Journal of Operational Research*, 2007.

[61] Gregor Giebel, Richard Brownsword, George Kariniotakis, Michael Denhard, and Caroline Draxl. The state-of-the-art in short-term prediction of wind power: A literature overview. Technical report, ANEMOS. plus, 2011.

[62] Dong C. Park, M.A. El-Sharkawi, R.J. Marks, L.E. Atlas, and M.J. Damborg. Electric load forecasting using an artificial neural network. *IEEE Transactions on Power Systems*, 1991.

[63] Yurii Nesterov, Arkadii Nemirovskii, and Yinyu Ye. *Interior-point polynomial algorithms in convex programming*. SIAM, 1994.

[64] National Renewable Energy Laboratory. National solar radiation data base - 1991- 2010 update. `http://rredc.nrel.gov`. [Online accessed Fep., 2015].

[65] Southern California Edison. Regulatory information - sce load profiles. `http://www.sce.com/`. [Online accessed Fep., 2015].

[66] Stephen Boyd and Lieven Vandenberghe. *Convex optimization*. Cambridge university press, 2009.

[67] Eilyan Bitar, Pramod P Khargonekar, and Kameshwar Poolla. Systems and control opportunities in the integration of renewable energy into the smart grid. In *IFAC World Congress*, 2011.

[68] U.S. Department of Energy. The smart grid: An introduction. `http://www.energy.gov/`. [Online accessed March, 2015].

[69] Na Li, Lijun Chen, and Steven H Low. Optimal demand response based on utility maximization in power networks. In *Power and Energy Society General Meeting*. IEEE, 2011.

[70] Shengnan Shao, Manisa Pipattanasomporn, and Saifur Rahman. Grid integration of electric vehicles and demand response with customer choice. *IEEE Transactions on Smart Grid*, 2012.

[71] Zhao Tan, Peng Yang, and Arye Nehorai. An optimal and distributed demand response strategy with electric vehicles in the smart grid. *IEEE Transactions on Smart Grid*, 2014.

[72] JS Vardakas, N Zorba, and CV Verikoukis. A survey on demand response programs in smart grids: Pricing methods and optimization algorithms. *IEEE Communications Surveys & Tutorials*, 2015.

[73] Mohamed H Albadi and EF El-Saadany. A summary of demand response in electricity markets. *Electric Power Systems Research*, 2008.

[74] Pierluigi Siano. Demand response and smart gridsâĂŤa survey. *Renewable and Sustainable Energy Reviews*, 2014.

[75] U.S. Department of Energy. Evaluating electric vehicle charging impacts and customer charging behaviors. `http://www.energy.gov/`. [Online accessed March, 2015].

[76] Fanxin Kong, Chuansheng Dong, Xue Liu, and Haibo Zeng. Blowing hard is not all we want: Quantity vs quality of wind power in the smart grid. In *INFOCOM*. IEEE, 2014.

[77] Fanxin Kong, Chuansheng Dong, Xue Liu, and Haibo Zeng. Quantity versus quality: Optimal harvesting wind power for the smart grid. *Proceedings of the IEEE*, 2014.

[78] Tamer Basar and Geert Jan Olsder. *Dynamic noncooperative game theory*. SIAM, 1995.

[79] Zhonghao Sun, Fanxin Kong, Xue Liu, Xingshe Zhou, and Xi Chen. Intelligent joint spatio-temporal management of electric vehicle charging and data center power consumption. In *International Green Computing Conference*. IEEE, 2014.

[80] A Subramanian, M Garcia, A Dominguez-Garcia, D Callaway, K Poolla, and P Varaiya. Real-time scheduling of deferrable electric loads. In *ACC*. IEEE, 2012.

[81] Ricardo J Bessa, Manuel A Matos, Filipe Joel Soares, and João A Peças Lopes. Optimized bidding of a ev aggregation agent in the electricity market. *IEEE Transactions on Smart Grid*, 2012.

[82] Habiballah Rahimi-Eichi and Mo-Yuen Chow. Auction-based energy management system of a large-scale phev municipal parking deck. In *Energy Conversion Congress and Exposition*. IEEE, 2012.

[83] Matteo Vasirani, Ramachandra Kota, Renato LG Cavalcante, Sascha Ossowski, and Nicholas R Jennings. An agent-based approach to virtual power plants of wind power generators and electric vehicles. *IEEE Transactions on Smart Grid*, 2013.

[84] Eilyan Bitar and Yunjian Xu. On incentive compatibility of deadline differentiated pricing for deferrable demand. In *Annual Conference on Decision and Control*. IEEE, 2013.

[85] Li Zhang, Faryar Jabbari, Tim Brown, and Scott Samuelsen. Coordinating plug-in electric vehicle charging with electric grid: Valley filling and target load following. *Journal of Power Sources*, 2014.

[86] Anna Nagurney. *Network economics: A variational inequality approach*. Springer Science & Business Media, 1998.

[87] Xue Liu, Qixin Wang, Wenbo He, Marco Caccamo, and Lui Sha. Optimal real-time sampling rate assignment for wireless sensor networks. *ACM Transactions on Sensor Networks*, 2006.

[88] Weihuan Shu, Xue Liu, Zonghua Gu, and Sathish Gopalakrishnan. Optimal sampling rate assignment with dynamic route selection for real-time wireless sensor networks. In *Real-Time Systems Symposium*. IEEE, 2008.

[89] Daniel O'Neill, Marco Levorato, Andrea Goldsmith, and Urbashi Mitra. Residential demand response using reinforcement learning. In *International Conference on Smart Grid Communications*. IEEE, 2010.

[90] Steven H Low and David E Lapsley. Optimization flow controlâĂŤi: basic algorithm and convergence. *IEEE/ACM Transactions on Networking*, 1999.

[91] Srinivas Shakkottai and Rayadurgam Srikant. *Network optimization and control*. Now Publishers Inc, 2008.

[92] Drew Fudenberg and Jean Tirole. Game theory. *MIT Press*, 1991.

[93] Roy D. Yates. A framework for uplink power control in cellular radio systems. *IEEE Journal on Selected Areas in Communications*, 1995.

[94] Noam Nisan, Tim Roughgarden, Eva Tardos, and Vijay V Vazirani. *Algorithmic game theory*. Cambridge University Press, 2007.

[95] Zhenhua Liu, Adam Wierman, Yuan Chen, Benjamin Razon, and Niangjun Chen. Data center demand response: Avoiding the coincident peak via workload shifting and local generation. *Performance Evaluation*, 2013.

[96] Nissan Leaf. Charging & range. `http://www.nissanusa.com/`. [Online accessed Fep., 2015].

[97] Tesla Motors. Model S. `http://www.teslamotors.com/models`. [Online accessed March, 2015].

[98] U.S. Department of Energy. Developing infrastructure to charge plug-in electric vehicles. `http://www.afdc.energy.gov/`. [Online accessed March, 2015].

[99] Roberto Cominetti, José R Correa, and Nicolás E Stier-Moses. Network games with atomic players. In *Automata, Languages and Programming*. Springer, 2006.

[100] V-charge: Automated valet parkging and charging for e-mobility collaborative project no. fp7-269916. `http://www.v-charge.eu/`. [Online accessed Apr., 2015].

[101] Julian de Hoog, Tansu Alpcan, Marcus Brazil, Doreen Anne Thomas, and Iven Mareels. Optimal charging of electric vehicles taking distribution network constraints into account. *IEEE Transactions on Power Systems*, 2014.

[102] Olle Sundstrom and Carl Binding. Flexible charging optimization for electric vehicles considering distribution grid constraints. *IEEE Transactions on Smart Grid*, 2012.

[103] Shizhen Zhao, Xiaojun Lin, and Minghua Chen. Peak-minimizing online ev charging. In *Allerton*, 2013.

[104] Lei Zhang and Yaoyu Li. Optimal management for parking-lot electric vehicle charging by two-stage approximate dynamic programming. *IEEE Transactions on Smart Grid*, 2017.

[105] Miadreza Shafie-khah, Ehsan Heydarian-Forushani, Gerardo J Osório, Fábio AS Gil, Jamshid Aghaei, Mostafa Barani, and João PS Catalão. Optimal behavior of electric vehicle parking lots as demand response aggregation agents. *IEEE Transactions on Smart Grid*, 2016.

[106] Nilufar Neyestani, Maziar Yazdani Damavandi, Miadreza Shafie-Khah, Anastasios G Bakirtzis, and João PS Catalão. Plug-in electric vehicles parking lot equilibria with energy and reserve markets. *IEEE Transactions on Power Systems*, 2017.

[107] Bogdan Doytchinov, John Lehoczky, and Steven Shreve. Real-time queues in heavy traffic with earliest-deadline-first queue discipline. *Annals of Applied Probability*, 2001.

[108] Vivek Sharma, Arun Thomas, Tarek Abdelzaher, Kevin Skadron, and Zhijian Lu. Power-aware qos management in web servers. In *RTSS*. IEEE, 2003.

[109] Francis YL Chin and Stanley PY Fung. Improved competitive algorithms for online scheduling with partial job values. *Theoretical computer science*, 2004.

[110] Hua Qin and Wensheng Zhang. Charging scheduling with minimal waiting in a network of electric vehicles and charging stations. In *VANET*. ACM, 2011.

[111] Julian Timpner and Lars Wolf. Efficient charging station scheduling for an autonomous parking and charging system. In *VANET*. ACM, 2012.

[112] Marek Chrobak, Leah Epstein, John Noga, Jiří Sgall, Rob van Stee, Tomáš Tichỳ, and Nodari Vakhania. Preemptive scheduling in overloaded systems. In *International Colloquium on Automata, Languages, and Programming*. Springer, 2002.

[113] Francis YL Chin and Stanley PY Fung. Online scheduling with partial job values: Does timesharing or randomization help? *Algorithmica*, 2003.

[114] Mohammad Charkhgard and Mohammad Farrokhi. State-of-charge estimation for lithium-ion batteries using neural networks and ekf. *IEEE Transactions on Industrial Electronics*, 2010.

[115] Yinjiao Xing, Wei He, Michael Pecht, and Kwok Leung Tsui. State of charge estimation of lithium-ion batteries using the open-circuit voltage at various ambient temperatures. *Applied Energy*, 2014.

[116] Enrico H Gerding, Valentin Robu, Sebastian Stein, David C Parkes, Alex Rogers, and Nicholas R Jennings. Online mechanism design for electric vehicle charging. In *AAMAS*. IFAAMAS, 2011.

[117] Anna Nagurney. *Network economics: A variational inequality approach*. Springer Science & Business Media, 2013.

[118] Kwon Oh-Heum and Chwa Kyung-Yong. Scheduling parallel tasks with individual deadlines. *Theoretical Computer Science*, 1999.

[119] Martin Stigge and Wang Yi. Graph-based models for real-time workload: A survey. *Real-Time Systems Journal*, 2015.

[120] Jane WS Liu, Wei-Kuan Shih, Kwei-Jay Lin, Riccardo Bettati, and J-Y Chung. Imprecise computations. *Proceedings of the IEEE*, 1994.

[121] Bu-808: How to prolong lithium-based batteries. `http://batteryuniversity.com/`. [Online accessed Apr., 2016].

[122] Elisabeth Günther, Olaf Maurer, Nicole Megow, and Andreas Wiese. A new approach to online scheduling: Approximating the optimal competitive ratio. In *SODA*. SIAM, 2013.

[123] Marek Chrobak, Leah Epstein, John Noga, JiřıÌĄ Sgall, Rob van Stee, Tomáš Tichỳ, and Nodari Vakhania. Preemptive scheduling in overloaded systems. *Journal of Computer and System Sciences*, 2003.

[124] Hans Kellerer, Ulrich Pferschy, and David Pisinger. *Knapsack problems*. Springer, 2004.

[125] Bala Kalyanasundaram and Kirk Pruhs. Speed is as powerful as clairvoyance. *Journal of the ACM*, 2000.

[126] Cynthia A Phillips, Cliff Stein, Eric Torng, and Joel Wein. Optimal time-critical scheduling via resource augmentation. In *STOC*. ACM, 1997.

[127] IBM. CPLEX optimizer. `http://www.ibm.com/`. [Online accessed Fep., 2015].

[128] Jonathan D Adler, Pitu B Mirchandani, Guoliang Xue, and Minjun Xia. The electric vehicle shortest-walk problem with battery exchanges. *Networks and Spatial Economics*, 2016.

[129] Daehyun Ban, George Michailidis, and Michael Devetsikiotis. Demand response control for phev charging stations by dynamic price adjustments. In *ISGT*. IEEE, 2012.

[130] Myriam Neaimeh, Graeme A Hill, Yvonne Hübner, and Phil T Blythe. Routing systems to extend the driving range of electric vehicles. *IET Intelligent Transport Systems*, 2013.

[131] Jochen Eisner, Stefan Funke, and Sabine Storandt. Optimal route planning for electric vehicles in large networks. In *AAAI*, 2011.

[132] Hao Liang, Isha Sharma, Weihua Zhuang, and Kankar Bhattacharya. Plug-in electric vehicle charging demand estimation based on queueing network analysis. In *PES General Meeting*. IEEE, 2014.

[133] Valentin Robu, Enrico H Gerding, Sebastian Stein, David C Parkes, Alex Rogers, and Nicholas R Jennings. An online mechanism for multi-unit demand and its application to plug-in hybrid electric vehicle charging. *Journal of Artificial Intelligence Research*, 2013.

[134] Valentin Robu, Sebastian Stein, Enrico H Gerding, David C Parkes, Alex Rogers, and Nicholas R Jennings. An online mechanism for multi-speed electric vehicle charging. In *AMMA*. Springer, 2012.

[135] Yijia Cao, Shengwei Tang, Canbing Li, Peng Zhang, Yi Tan, Zhikun Zhang, and Junxiong Li. An optimized ev charging model considering tou price and soc curve. *IEEE Transactions on Smart Grid*, 2012.

[136] Reuven Cohen, Liran Katzir, and Danny Raz. An efficient approximation for the generalized assignment problem. *Information Processing Letters*, 2006.

[137] Lisa Fleischer, Michel X Goemans, Vahab S Mirrokni, and Maxim Sviridenko. Tight approximation algorithms for maximum general assignment problems. In *SODA*. ACM, 2006.

[138] Wikipedia. Generalized assignment problem. `http://en.wikipedia.org/wiki/Generalized_assignment_problem`. [Online accessed Fep., 2015].

[139] OpenStreetMap. http://www.openstreetmap.org/. [Online accessed Fep., 2015].

[140] DLR-Institute of transportation systems. SUMO-Simulation of urban mObility. http://dlr.de/ts/sumo. [Online accessed Fep., 2015].

[141] Federal Energy Regulatory Commission. Electric power markets: National overview. http://www.ferc.gov/. [Online accessed Fep., 2015].