DESIGN AND SIMULATION OF SOLAR BASED FAST CHARGING STATION FOR ELECTRIC VEHICLE USING MATLAB

Saima Shafi Choudhary[1], Er Baljit Kaur [2]

Post Graduate Student, Electrical Engineering Dept., IET Bhaddal Punjab India.
Assistant Professor, Electrical Engineering Dept. IET Bhaddal Punjab India.

***

Abstract - *The transition towards sustainable transportation solutions has led to an increased demand for electric vehicles (EVs). One of the critical challenges in EV adoption is the availability of efficient and fast-charging infrastructure. This paper presents the design and simulation of a solar-based fast charging station for electric vehicles using MATLAB. The proposed system integrates solar photovoltaic (PV) panels, power electronics, energy storage, and charging management techniques to provide a reliable and sustainable solution. The design process involves selecting appropriate PV panel configurations and sizing them to generate the required power for fast charging. To ensure continuous power availability, an energy storage system, such as batteries, is integrated into the system. The power electronics components, including DC-DC converters and inverters, are designed to efficiently manage power flow between the PV panels, energy storage, and the EV charging units. Advanced control strategies are implemented to regulate the charging process, considering factors like battery state of charge, EV battery specifications, and grid interactions.*

Key Words**: Electric Vehicle Charging Station, Solar EV charging, Wireless EV Charging System, MATLAB EV charging station.**

1. INTRODUCTION

With the growing demand for sustainable transportation, electric vehicles (EVs) have emerged as a promising solution to reduce greenhouse gas emissions and combat climate change. To encourage the adoption of EVs, the establishment of efficient and eco-friendly charging infrastructure is crucial. One innovative approach is the design and simulation of a solar-based fast charging station for electric vehicles. The goal of this project is to create a charging station that harnesses solar energy to provide fast and renewable charging solutions for EV owners. By integrating solar power into the charging station, we aim to reduce dependency on the conventional grid and decrease the carbon footprint associated with EV charging. During recent years, there have been changes in Ecuador about the energy matrix. New hydropower projects have been carried out to reduce CO2 emissions that pollute the environment. This, in turn, has opened recent technologies in which the country wants to be involved, such as electric vehicles [1], [2] which contribute, among other things, to a reduction in pollution by greenhouse gases [3]. The electric vehicle (EV) revolution refers to the ongoing global transformation in the automotive industry, characterized by a significant shift towards the adoption of electric vehicles powered by electricity instead of traditional internal combustion engines fueled by gasoline or diesel. This revolution is driven by various factors and has far-reaching implications for the environment, energy consumption, and the automotive sector. The primary driver of the EV revolution is the growing awareness of the environmental impact of fossil fuel-powered vehicles. Electric vehicles produce zero tailpipe emissions, reducing greenhouse gas emissions and improving air quality in urban areas. Significant advancements in battery technology have led to improvements in EV range, charging speed, and cost-effectiveness. Lithium-ion batteries have become the dominant technology for EVs, making them more practical and attractive to consumers. Many governments around the world have implemented policies, incentives, and regulations to promote the adoption of electric vehicles. These measures include financial incentives, tax credits, rebates, and stricter emissions standards for conventional vehicles. The cost of battery production has been decreasing steadily over the years, making electric vehicles more affordable for consumers. As economies of scale continue to drive down battery costs, EVs are becoming more competitive with internal combustion engine vehicles in terms of upfront prices. Technological advancements in electric drivetrains, charging infrastructure, and autonomous driving features have made electric vehicles more appealing and convenient to consumers. Growing public awareness of climate change and environmental issues, coupled with a positive perception of EVs as futuristic and eco-friendly vehicles, has driven consumer interest in electric mobility.

2. RELATED WORK

There have been various research studies, pilot projects, and developments related to solar-powered microgrid-connected wireless electric vehicle (EV) charging systems. Below are some key examples of existing work in this area: With the increasing interest in green technologies in transportation, plug-in hybrid electric vehicles (PHEV) have proven to be the best short-term solution to minimize greenhouse gas emissions [1]. In [2] Electric vehicle charging infrastructure is hitting the stage where its impact on the performance and operation of power systems becomes more and more pronounced. Concept of V2G (Vehicle to Grid) that electric vehicles could act as a new power source for the grid was proposed [3]. A solar PV power system consists of a PV Module, a DC-DC boost converter, and an Adaptive Neuro-Fuzzy Inference System (AN FIS) based MPPT controller developed in MATLAB/Simulink [4]. [5] presents a wireless charging infrastructure based on Inductive Power Transfer (IPT) for semi-fast charging of light-duty (LD) EVs. [5][6] presents an active balancing topology for large-scale battery packs in a heavy electric vehicle. In order to investigate the performance of the system, a battery pack and Bidirectional Flyback Converter (BiFLC) based active balancing circuit equipped with Switch Matrix (SwM) have been simulated by using MATLAB/Simulink. A charge transfer bus, which is supplied by the first cell of the battery pack, is used to transfer energy between the source/ destination cells. Thus, the need for the auxiliary circuit/battery is eliminated. the existing research fails to adopt differentiated dynamic electricity price to guide the orderly charging of electric vehicles and dissipate the photovoltaic output, a strategy of vehicle and network interaction based on electric vehicle (EV) charging load space transfer is proposed [7]. Finally, the effectiveness of the proposed method [8][9] is verified by a practical example. Implementation of a suitable DC-DC converter for charging the battery plays a crucial role in the pathway of electric vehicle (EV) production [10][11].

3. OBJECTIVES AND PROBLEM FORMULATION.

The design objectives of a solar grid-connected electrified road for wireless charging of electric vehicles aim to create a sustainable and efficient charging infrastructure that integrates renewable energy with smart transportation solutions. The primary objective is to harness solar energy through photovoltaic (PV) panels integrated into the road infrastructure. This renewable energy will be used to charge electric vehicles wirelessly, reducing dependency on non-renewable energy sources and lowering greenhouse gas emissions [11][12]. The solar PV arrays must be designed to maximize energy generation efficiency, considering factors like solar panel orientation, tilt angle, and shading analysis to optimize solar exposure throughout the day. The electrified road should be connected to the electrical grid, allowing surplus energy generated by the solar panels to be fed back into the grid when the demand is low or stored for later use. Additionally, when solar energy production is insufficient, the grid can supply additional power to meet the changing demands of electric vehicles. The wireless charging technology used on the road should be efficient and capable of delivering power wirelessly to vehicles in a safe and controlled manner. It should support various electric vehicle models and charging standards. Implementing smart charging solutions can optimize the charging process by considering factors like energy demand, electricity pricing, and grid conditions. Smart charging can also prioritize charging for vehicles based on their battery levels and usage patterns.

The primary objective of this project is to develop a solar grid-connected electrified road system that enables wireless charging of electric vehicles (EVs) while they are in motion or stationery. The goal is to create a sustainable and efficient charging infrastructure that promotes widespread adoption of EVs and reduces the dependence on traditional fossil-fuel-based transportation. The project aims to design and implement a solar photovoltaic (PV) array system along the road's surface or in adjacent structures to harvest solar energy. The challenge lies in optimizing the PV system's efficiency, considering factors like varying sunlight conditions, shading, weather patterns, and the road's available surface area for solar panels. Efficient integration of the solar energy generated with the existing power grid is crucial to ensure a continuous and reliable power supply for the charging system. The development of a robust and efficient wireless charging system is a core aspect of the project. The wireless charging infrastructure must be able to transfer power effectively to EVs moving at various speeds while ensuring safety and minimizing energy losses. The system should also support bi-directional power transfer, allowing EVs to feed excess energy back to the grid when needed, contributing to grid stability. Designing an electrified road surface that can accommodate wireless charging without compromising road safety and integrity is a significant challenge. The project should consider the road's durability, ability to withstand heavy traffic, and the impact of weather conditions on the charging efficiency. Safety standards and protocols for electrified roads must be established to prevent accidents and ensure public trust in technology. Achieving high charging efficiency is vital to minimize energy losses during wireless charging. Additionally, the project should address the grid's capability to manage the increased load from multiple EVs charging simultaneously, especially during peak hours. Energy storage systems, such as batteries or supercapacitors, might be integrated to buffer the grid and improve charging efficiency. The project should perform a comprehensive cost analysis, considering the installation, maintenance, and operational costs of the solar grid-connected electrified road system. An economic feasibility study will help determine the return on investment and assess the system's potential for commercial deployment. Evaluating the environmental benefits of the solar grid-connected electrified road is essential. The project should conduct a life-cycle assessment to compare the system's carbon footprint with conventional charging methods and internal combustion engine vehicles. Additionally, addressing potential environmental impacts, such as land use and recyclability of components, is crucial for long-term sustainability. The project needs to consider existing regulations and policies related to road infrastructure, electric vehicle charging, and renewable energy integration. Identifying any legal barriers or incentives can help guide the project's implementation and ensure compliance with relevant standards.

4. METHODOLOGY.

The wireless charging system for electric vehicles typically consists of two main components:

4.1. Charging Pad Transmitter Coil:

This component is installed on the ground or inside a charging station. It is responsible for generating an alternating magnetic field using an alternating current (AC) power source as shown in figure below.

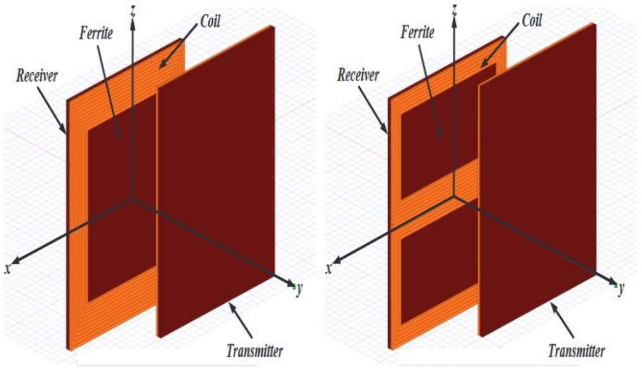

Figure 1: Simulation model of the wireless power transmitter and Receiver in a 3-Dimensional Coordinate system.

structures

4.2. Vehicle Receiver Coil:

This component is integrated into the electric vehicle and is positioned underneath the vehicle's chassis. The receiver coil is designed to pick up the magnetic field generated by the charging pad and convert it back into electrical energy as shown in figure below.

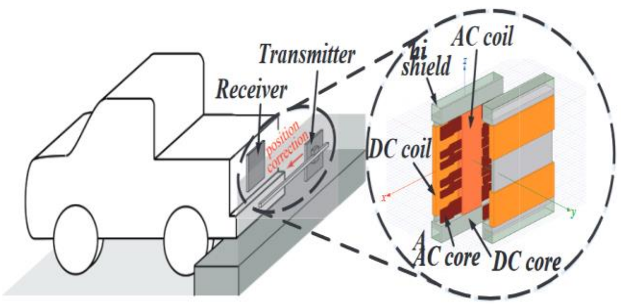

Figure 2: The proposed system is intended for the rear of an EV. Each charging pad is composed of two coils: a dc and ac coil.

The process of wireless power transfer in electric vehicle charging involves the following steps:

1. The charging station is connected to an AC power supply or a solar connected microgrid.
2. The AC power from the supply is converted to a higher frequency AC using power electronics, typically in the range of tens to hundreds of kilohertz.
3. The high-frequency AC is fed into the charging pad transmitter coil, which generates an alternating magnetic field around it.
4. When the electric vehicle is parked over the charging pad, the receiver coil in the vehicle's undercarriage is brought into proximity with the magnetic field. As a result of electromagnetic induction, an electrical current is induced in the receiver coil.
5. The induced current in the receiver coil is rectified and converted to direct current (DC) using power electronics.
6. The DC electricity is then used to charge the electric vehicle's battery, which powers the vehicle's electric motor.

5. RESULTS.

Designing and simulating a solar energy-based fast charging station for electric vehicles using MATLAB would involve various steps and components, such as solar panels, battery storage, power electronics, and control systems.

The experimental and simulated results obtained during the project work are briefly explained.

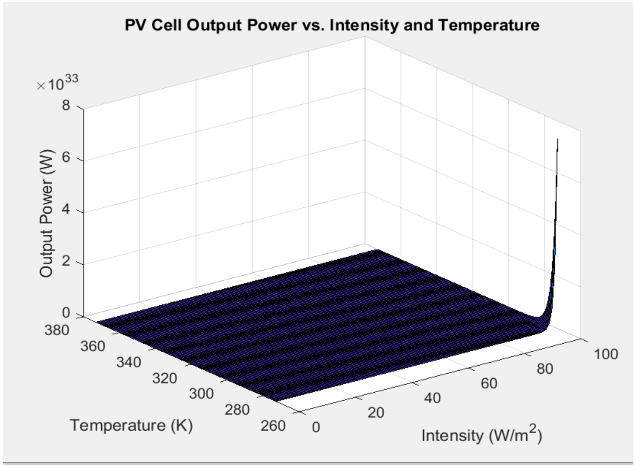

Figure 3: PV Cell Output Power vs. Intensity and Temperature

Figure 3. defines several parameters that affect the behavior of the PV cell. These include properties of the cell itself and environmental factors:

Iph: Photocurrent, the current produced by the PV cell when illuminated.

I0: Saturation current, a parameter related to the cell's intrinsic properties.

n: Ideality factor, representing the non-ideal behavior of the cell.

Rs: Series resistance, representing internal losses.

Rsh: Shunt resistance, also related to internal losses.

k: Boltzmann constant, involved in the temperature effect.

T: Temperature in Kelvin.

q: Elementary charge, related to electron movement.

A: Area of the PV cell.

G: Sunlight intensity (W/m^2), ranging from 0 to 1000.

Tc: Temperature in Celsius, ranging from 0°C to 100°C.

Figure 3. calculates the output power of the PV cell for different combinations of sunlight intensity (G) and temperature (Tc). For each combination.

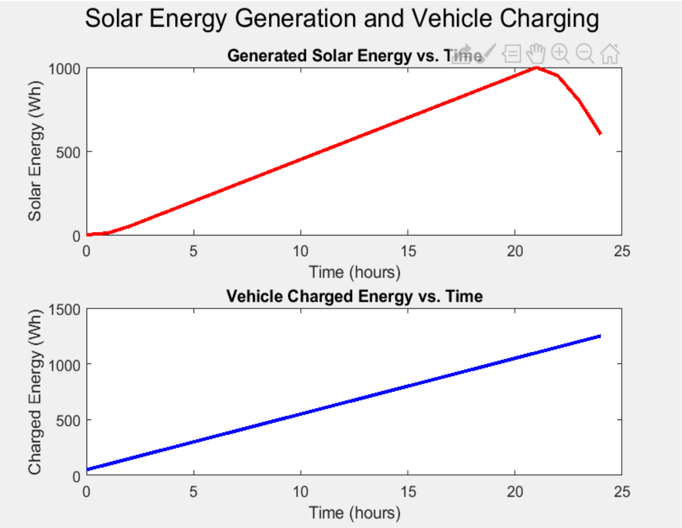

Figure 4: Solar Energy Generation and Vehicle Charging. a). Generated Solar Energy vs. Time. b). Vehicle Charged Energy vs. Time.

Figure 4. (a). illustrates how the amount of solar energy produced by solar panels changes over a specific period. The x-axis represents time, usually measured in hours, while the y-axis represents the amount of energy generated by the solar panels, typically measured in Watt-hours (Wh). The horizontal axis represents time. Each point on the x-axis corresponds to a specific time interval, often in hours. The vertical axis represents the amount of energy generated by solar panels. This energy is usually measured in Watt-hours (Wh) or kilowatt-hours (kWh). Each point on the y-axis corresponds to the amount of energy generated by the solar panels during a specific time interval. The line on the graph represents the trend of generated solar energy throughout the day. It typically rises as the sun comes up, reaches a peak around midday when sunlight is the strongest, and then decreases as the sun sets. This line helps visualize how solar energy generation varies based on daylight hours and sunlight intensity.

Figure 4. (b). shows how much energy is used to charge an electric vehicle over a specific period. Like the previous graph, the x-axis represents time, and the y-axis represents energy, usually measured in Watt-hours (Wh) or kilowatt-hours (kWh). Like the previous graph, the x-axis represents time intervals, usually in hours. The points on the x-axis correspond to different times throughout the day. The vertical axis represents the cumulative amount of energy used to charge the electric vehicle. This is the total energy transferred to the vehicle's battery. It increases over time as the vehicle charges. The line on the graph represents the trend of charged energy over time. It starts at zero (when the charging begins) and increases as the vehicle's battery charges. The slope of the line indicates the charging rate; a steeper slope indicates faster charging.

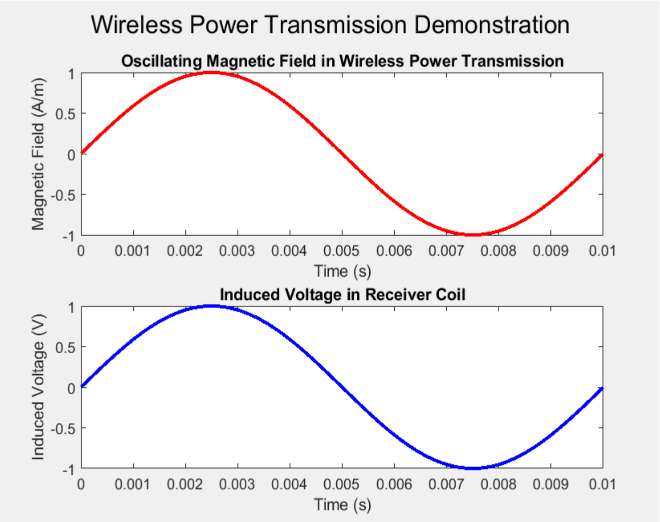

Figure 5. Wireless Power Transmission a). Oscillating Magnetic Field in Wireless Power Transmission. b). Induced Voltage in Receiver Coil.

Figure 5 (a) generates an oscillating magnetic field, which represents the electromagnetic waves generated by the transmitter coil in a wireless power transmission system. The magnetic field's strength varies sinusoidally over time. This field is what induces the voltage in the receiver coil.

In Figure 5 (b). The induced voltage in the receiver coil is calculated using Faraday's law of electromagnetic induction. The induced voltage is proportional to the rate of change of the magnetic field strength. As the magnetic field oscillates, it induces a corresponding voltage in the receiver coil.

Comparing different power transfer techniques for a solar-based wireless electric vehicle charging system can involve various parameters and factors. Figure 5.6. illustrates a graphical comparison of two hypothetical power transfer techniques: Inductive Power Transfer (IPT) and Resonant Inductive Coupling (RIC).

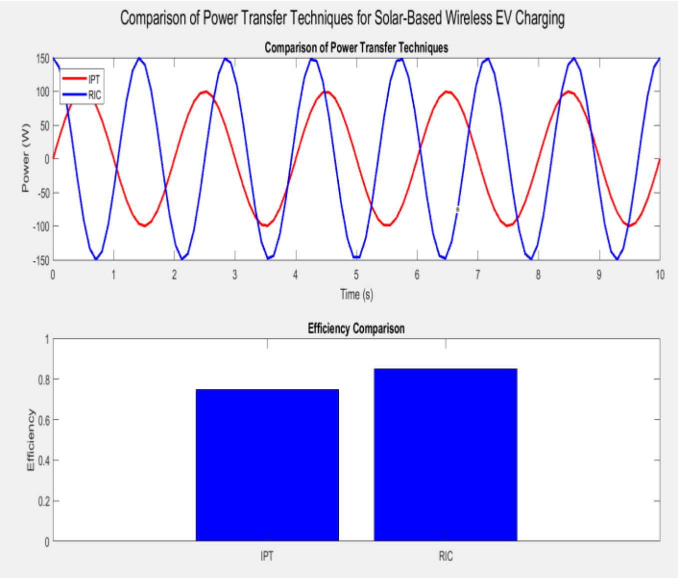

Figure 6: Comparison of Power Transfer Techniques for Solar-Based Wireless EV Charging a). Comparison of Power Transfer Techniques b). Efficiency Comparison.

In Figure 6 (a). The x-axis represents time, typically measured in seconds. The y-axis represents power, typically measured in watts (W). Two lines, one in red (IPT) and one in blue (RIC), represent the power profiles of two different power transfer techniques. These profiles show how the power being transferred between the charging station and the EV changes over time. This graph illustrates the dynamic nature of power transfer using these techniques. You can observe the fluctuating power levels over the given time interval. In Figure 6 (b). The x-axis represents the two power transfer techniques, namely "IPT" (Inductive Power Transfer) and "RIC" (Resonant Inductive Coupling). The y-axis represents efficiency, often in decimal form (e.g., 0.85 for 85%). Two bars, one corresponding to IPT and the other to RIC, show the efficiency of each technique. This graph allows you to quickly compare the efficiency of the two techniques. Higher efficiency indicates a more effective utilization of the transferred power.

In Figure 7 (a). Battery charge level, often referred to as State of Charge (SoC) is illustrated, which indicates the amount of energy stored in a battery compared to its maximum capacity. It's usually expressed as a percentage. For example, if a battery's maximum capacity is 100 kWh and it currently holds 50 kWh, the SoC would be 50%.

Battery charge level is a critical parameter in electric vehicles and other battery-powered systems. It helps users understand how much energy is available for use and whether the battery needs charging. Monitoring the battery's charge level helps prevent over-discharging, which can damage the battery, and ensures the vehicle or system is operated within its safe and efficient range.

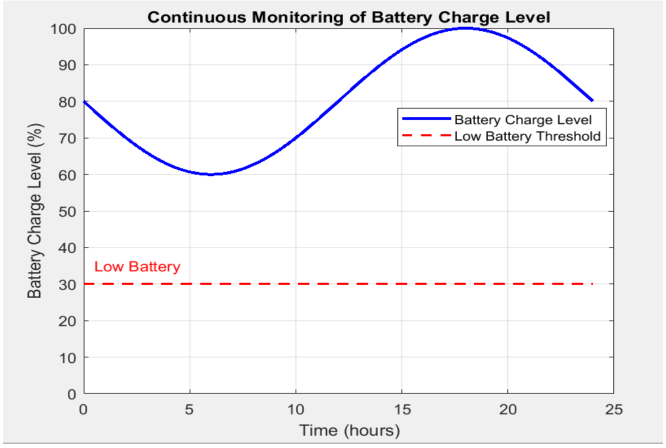

Figure 7: Continuous Monitoring of Battery Charge Level a). Battery Charge Level b). Low Battery Threshold

In Figure 7 (b). The low battery threshold is a predefined value of battery charge level, usually expressed as a percentage, below which the system considers the battery to be low on charge. It's a critical point used to trigger various actions, such as warnings to the user, energy-saving measures, or initiating charging. For instance, a low battery threshold set at 20% might indicate that the battery is running low, prompting the user to charge the vehicle or take measures to conserve energy.

5. CONCLUSIONS

This study showcases the successful integration of MATLAB-based simulation techniques in designing a fast-charging station for electric vehicles. The simulation results provide valuable insights into the station's performance, efficiency, safety, and grid compatibility. As the world transitions towards a more sustainable transportation ecosystem, the development of reliable and efficient charging infrastructure, as demonstrated in this study, plays a pivotal role in accelerating the adoption of electric vehicles.

REFERENCES

[1]. M. C. Kisacikoglu, A. Bedir, B. Ozpineci, and L. M. Tolbert, “PHEV- EV charger technology assessment with an emphasis on V2G operation,” Oak Ridge Nat. Lab., Tech. Rep. ORNL/TM-2010/221, Mar. 2012.

[2]. D. Berjoza and I. Jurgena, “Analysis of distribution of electric vehicle charging stations in the Baltic,” Eng. Rural Develop., vol. 14, no. January, pp. 258–264, 2015.

[3] I. Zenginis, J. S. Vardakas, N. Zorba, and C. V. Verikoukis, “Analysis and quality of service evaluation of a fast-charging station for electric vehicles,” Energy, vol. 112, pp. 669–678, 2016.

[4] P. Fan, B. Sain Bayar, and S. Ren, “Operation analysis of fast charging stations with energy demand control of electric vehicles,” IEEE Trans. Smart Grid, vol. 6, no. 4, pp. 1819–1826, 2015.

[5] K. Yunus, H. Z. De La Parra, and M. Reza, “Distribution grid impact of plug-in electric vehicles charging at fast charging stations using stochastic charging model,” in Proc. 14th Eur. Conf. Power Electron. Appl., Aug 2011.

[6] E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany, and A. Zidan, “Un- coordinated charging impacts of electric vehicles on electric distribution grids: Normal and fast charging comparison,” in IEEE Power Energy Soc. General Meeting, July 2012.

[7] Q. Yang, S. Sun, S. Deng, Q. Zhao, and M. Zhou, “Optimal sizing of PEV fast charging stations with markovian demand characterization,” IEEE Trans. Smart Grid, in press.

[8] C. Farkas and M. Telek, “Capacity planning of electric car charging station based on discrete time observations and map (2)/g/c queue,” Period. Polytech., Electr. Eng. Comput. Sci., vol. 62, no. 3, pp. 82–89, 2018.

[9] E. Wood, S. Raghavan, C. Rames, J. Eichman, and M. Melaina, “Regional charging infrastructure for plug-in electric Massachusetts,” Nat. Renewable Energy Lab. (NREL), Golden, CO, Tech. Rep. DOE/GO- 102016-4922, 2017.

[10] E. Wood, C. Rames, M. Muratori, S. Raghavan, and M. Melaina, “Na- tional plug-in electric vehicle infrastructure analysis,” Nat. Renewable Energy Lab. (NREL), Golden, CO, Tech. Rep. DOE/GO-102017-5040, 2017.

[11] U.S. Dept. Transport., “Smart city challenge,” https://www. transportation.gov/smart city, [Online; accessed 09-Aug-2018].

[12] Alternative Fuels Data Center, “Electric vehicle infrastructure projection tool (evi-pro) lite,” https://www.afdc.energy.gov/evi-pro-lite, [Online; accessed 09-Aug-2018].

[13] H. Zhang, Z. Hu, Z. Xu, and Y. Song, “Optimal planning of PEV charging station with single output multiple cables charging spots,” IEEE Trans. Smart Grid, vol. 8, no. 5, pp. 2119–2128, 2017.

[14] Y. Xiang, J. Liu, R. Li, F. Li, C. Gu, and S. Tang, “Economic planning of electric vehicle charging stations considering traffic constraints and load profile templates,” Applied Energy, vol. 178, pp. 647–659, 2016.