

The potential of electric cars in smart grid energy storage systems (Vehicle to grid technology)

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Abstract— The main drivers for shifting from internal combustion engines to Electric Vehicles include greenhouse gas emissions, rapid disappearance of fossil fuel supplies, oil crisis and high cost of petroleum products. Concerning EVs' commercial deployment, a significant charging infrastructure is needed to enable the process of loading/unloading charges in and out of batteries. Vehicle-to-Grid is a modern technology that originated from the fact that numerous EVs can be loaded as well as an energy storage system to support the grid. The text introduces electrical vehicles technology, smart grid technology and power flow methodology under V2G scheme. It also examines the challenges associated with V2G technology and V2G services and benefits.

I. INTRODUCTION

The increase in GHG emission is an important global concern. High costs and substantial energy waste from voltage regulation, daily load demand fluctuations and frequency adjustments are the main reasons why operational efficiency of power grids is still unsatisfactory. In times where the amount of energy required surpasses that which can be supplied by base load power plants, peak load plants come into operation. Conversely, on days with minimal electricity needs, unwanted energy from base load generators ends up as waste. Also, Voltage/frequency control of this nature has high operating costs.

This issue can be solved through Vehicle to Grid (V2G) technology that uses electric vehicle's (EVs) extensive energy storage capacity as a buffer for both power grid and renewable sources of electricity. EVs can be attached to the smart grid either in V2G or G2V modes. The vehicle-to-grid involves flow of energy from EV to grid while grid-to-vehicle mode involves movement of electric charges from the grid to the EVs.

Smart grids and V2G systems are interconnected and have a symbiotic relationship between them. An important function is played by AC to DC (and vice versa) conversions during energy exchange processes. Energy storage systems in electric vehicles become very useful when exchanging electrical power with a grid system. as an example, when grid demand goes down sharply, the cars can take on extra energy overloads which in turn help to reduce power plant strains.

It is during low periods of network load demand that electric vehicles can be used as storage for excess electricity to avoid wastage. When prices drop, purchasers of EVs may prefer to

import power from the distribution companies only to sell them back during peak periods at high costs, thus providing a chance for gains.

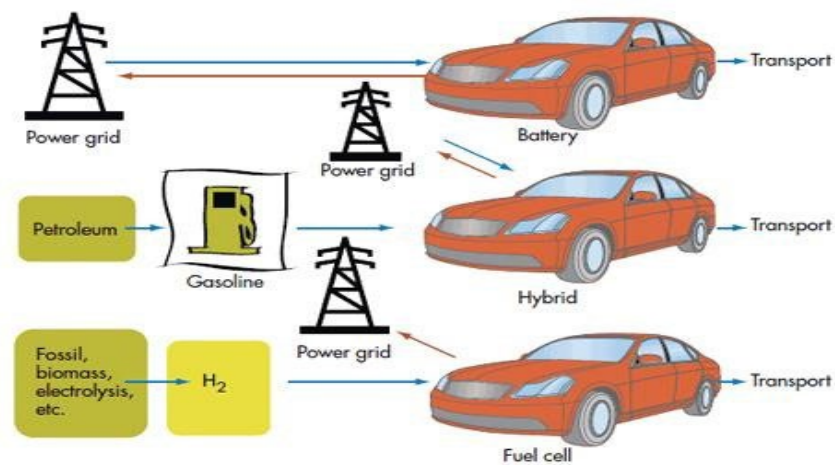


Fig. 1: The schematic diagram of V2G (Harighi et al., 2018).

II. LITERATURE REVIEW

2.1 Electrical Vehicle Technology

Electric vehicles (EVs) have lately experienced enormous technological advancements that make them strong rivals for traditional internal combustion engine vehicles (ICEVs). EV adoption is being encouraged by nations globally as a measure of reducing greenhouse gas emissions. For instance, Electric Vehicle Market in Jordan is expected to grow at a CAGR of 34.0% from 2019 to 2025. In Jordan, government initiatives like installing 3,000 charging stations and fiscal reliefs are stimulating the demand for electrical cars.

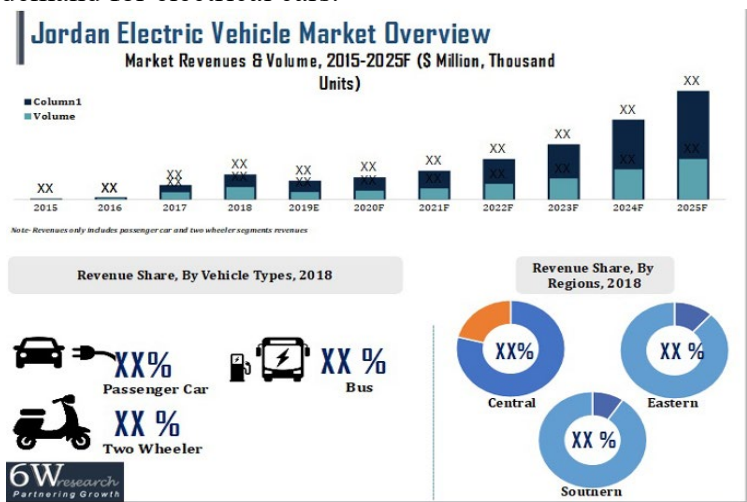


Fig. 2: Jordan Electric Vehicle Market Overview (Harighi et al., 2018)

The expansion of the electric vehicle (EV) market necessitates continuing research and development for wide EV adoption in days to come (Sarlioglu et al., 2017). Different types of EVs are available including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), plug-in electric vehicles (PEVs), and battery electric vehicles (BEVs). This study concentrates on BEVs, which run exclusively on battery power. The larger capacity batteries allow for greater range besides enabling compatibility with grid integration to use them as vehicle-to-grid (V2G) systems. Powertrain, energy storage systems (ESS) and charging infrastructure will be some key areas of EV development that will support future V2G scenarios (Yong et al., 2015).

2.1.1 Power Train

In an automotive system, the power train transfers drive from the engine to the axle. A Battery Electric Vehicle (BEV) operates simply using a battery as its source of power, where it is used for locomotion by an electric motor. The BEV power train consists of three main components namely: a battery; an electric motor; and a transmission. Figure 3 shows a basic power train diagram for a BEV (Sarlioglu et al., 2017).

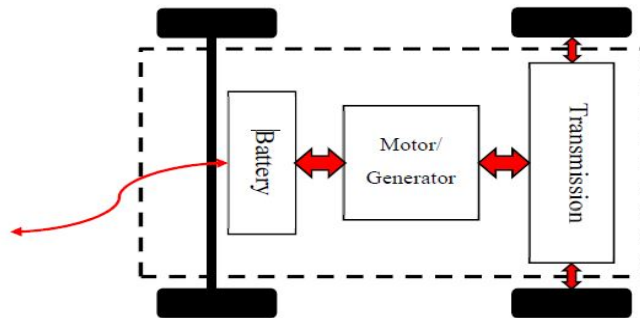


Fig. 3: Schematic diagram of BEV power train (Sarlioglu et al., 2017).

BEVs can be charged from external sources such as the electrical grid or regenerative braking (Ergon Energy, 2017). The focus in this study is limited provisionally to external charging techniques only but eliminates any reference to recharging batteries through regenerating braking in model construction.

2.1.2 Energy Storage System

As a car battery, the energy storage system (ESS), is an important part of Battery Electric Vehicles (BEVs). At present, batteries are one of the costliest components in BEV technology. However, there are limitations to battery technology that have hindered widespread EV adoption in the transport sector. Battery technologies are the best suited to attracting global attention towards electric vehicles in relation to matters concerning range, acceleration, and costs (Yong et al., 2015).

Ongoing research and experimentation has resulted in two main types of batteries for EVs – Nickel-Metal Hydride (NiMH) and Lithium-ion (Li-ion). Earlier on NiMH batteries were used but this changed with the advent of Li-ion batteries which revolutionized EV technology enabling long distance models as well as more powerful ones that can compete with traditional internal combustion engine vehicles (ICEVs) (Yong et al., 2015).

In today's market, major EV manufacturers predominantly utilize Li-ion batteries due to their the main Li-ion batteries user by leading manufacturers of electric cars today include having longer ranges, higher energy densities, affordability and being nontoxic among other advantages. Moreover, Li-ion also enables fast charging hence removing any concerns about lengthy charge times (Yong et al., 2015). Such major brands as Nissan Leaf, Mitsubishi i-MiEV, Tesla Model S and Chevrolet Bolt all feature Li-ion-battery-based ESS. Table I provides a comparison of NiMH and Li-ion cell types used in BEVs.

TABLE I
COMPARISON OF NiMH AND LI-ION CELL TYPES IN EVs (SARLIOGLU ET AL., 2017).

	NiMH BEV	Li-ion Plug-in Hybrid EVs - BEVs
Nominal cell voltage [V]	1.2	3.3-3.8
Energy density [Wh/l]	250	200-400
Specific Energy [Wh/kg]	100	120-200
Power density [W/l]	500-800	800-2200
Specific power [W/kg]	200-400	500-1200

There are some disadvantages associated with Li-ion batteries, such as the potential for fire or explosion if they malfunction (Battery University, 2022). Although this technology is still developing, it looks set to be an ideal battery solution for future EVs (Yong et al., 2015).

2.1.3 Charging infrastructure

Rectifiers are commonly included in electric vehicle (EV) chargers, i.e., AC-DC converters. Furthermore, DC-DC converter is also available in fast charging stations for better power conversion efficiency. The chargers can either be on-board or off-board depending on their configuration and the capacity of the charging (Yong et al., 2015)

The design of onboard chargers must be compact and lightweight to enable effective movement of an EV. However, one problem that they have is that they are low powered making them ideal only for slow charging purposes. In contrast, off-board chargers usually occupy specific locations thus being larger due to the presence of charger units incorporated with a rapid charger DC-DC converter (Yong et al., 2015).

Further still, there are global guidelines governing electric vehicles' recharging process. International Electromechanical Commission (IEC), Society of Automotive Engineers (SAE), CHAdeMO EV standards among others are some of the bodies that influence these regulations. This table II refers to SAE charging levels as per SAE electric vehicle conductive charge coupler standard (Insideevs,2017).

TABLE II
SAE CHARGING STANDARDS (INSIDEEVS,2017).

Charging level	Charge rating	Charge time	Remark
AC level 1	120 V, 1.4 kW (12 A) 120 V, 1.9 kW (16 A)	PHEV: 7 h (SOC-0% to full) BEV: 17 h (SOC-20% to full)	On-board charger
AC level 2	240 V, up to 19.2 kW (80 A)	For 3.3 kW charger: PHEV: 3 h (SOC-0% to full) BEV: 7 h (SOC-20% to full) For 7 kW charger: PHEV: 1.5 h (SOC-0% to full) BEV: 3.5 h (SOC-20% to full) For 20 kW charger: PHEV: 22 min (SOC-0% to full) BEV: 1.2 h (SOC-20% to full)	On-board charger
AC level 3	> 20 kW, single phase and three-phase	To be determined	To be determined
DC level 1	200-450 V _{DC} , up to 36 kW (80 A)	For 20 kW charger: PHEV: 22 min (SOC-0% to 80%) BEV: 1.2 h (SOC-20% to full)	Off-board charger
DC level 2	200-450 V _{DC} , up to 90 kW (200 A)	For 45 kW charger: PHEV: 10 min (SOC-0 to 80%) BEV: 20 min (SOC-20 to 80%)	Off-board charger
DC level 3	200-600 V _{DC} , up to 240 kW (400 A)	For 45 kW charger: BEV (only): <10 min (SOC-0 to 80%)	Off-board charger

Table II and Figure 4 show that DC fast charging systems can allow electric vehicle (EV) users to charge their vehicles in less than an hour, with some systems taking as low as 10 minutes to charge. Presently, DC fast charging systems are available in two power flow configurations: from the grid to the EVs and vice versa Wang et al. (2012).

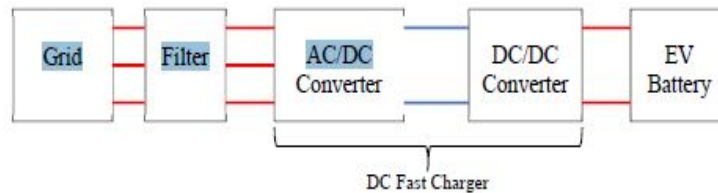


Fig. 4: Block diagram of DC fast charging station Wang et al. (2012).

A. The first kind is unidirectional DC fast charger which permits drawing power from the grid for recharging EV batteries. Its benefit is that it does not severely affect battery life span due to lesser recharging cycles (Channegowda et al., 2015). However, this kind of chargers can't be involved into V2G system when power from car flows back into the grid. In contrast, bi-directional DC quick chargers work both ways by being able to both charge and discharge

energy. Nonetheless, battery life is affected by bidirectional arrangement because more cycles are required (Channegowda et al., 2015)

2.2 Smart Grid

A smart grid is a comprehensive energy system that enables integration, two-way communication, and optimal control over formerly fragmented components of the electricity infrastructure for producers and consumers alike. By enabling information exchange and analysis, smart grids enhance the efficiency of electricity utilization (International Energy Agency, International Low-Carbon Energy Technology Platform, 2015).

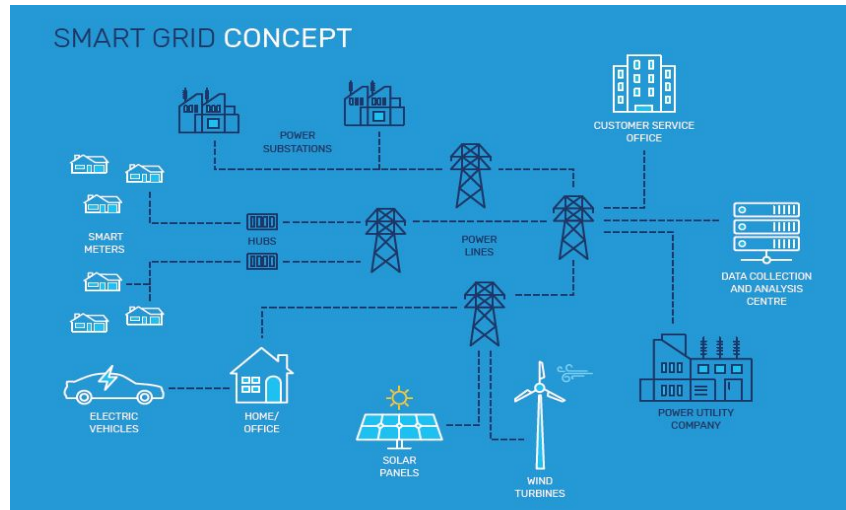


Fig. 5: Schematic diagram of smart grid (International Energy Agency, International Low-Carbon Energy Technology Platform, 2015).

Efficient electricity use and management are essential responses to increasing environmental protection requirements, including the imperative to reduce CO₂ emissions and reliance on primary energy resources. According to the SMARTer2030 report by The Global e-Sustainability Initiative, smart grid technology has the potential to reduce CO₂ emissions in the power sector by up to 15% by 2030 and generate an additional USD 0.8 trillion in income compared to 2015 (The Global e-Sustainability Initiative, 2015) .

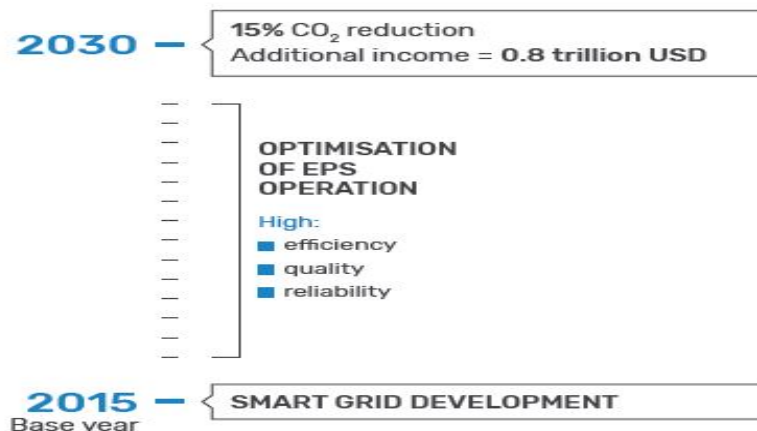


Fig. 7 Schematic diagram of smart grid development (The Global e-Sustainability Initiative, 2015).

2.3 State of the art V2G

2.3.1 Methods of Power flow for V2G

The integration of EVs with smart grids has undergone extensive development. However, only one-way power flow is considered; that is from the electric grid to the EV battery pack. This was because realization of unidirectional power flow did not require much development cost because of the presence of regular EV chargers modified with communication (Sortomme & El-Sharkawi, 2012). The idea was to use load shifting control for load management. In this case, electric vehicles were charged during off-peak hours. The more services we need from EV batteries, the more advanced devices are needed such as bidirectional chargers.

However, recently people started talking about bidirectional power flow between EV batteries and electric grid. This concept is known as vehicle-to-grid (V2G) technology. Electric cars can transfer electricity to/from the electric grid using this approach. The vehicle charges during times when consumer demand is low and discharges into the system when required urgently or in high demand periods. Additionally, more opportunities came up with bidirectional V2G which prompted industry and utilities companies to advocate V2G concept on a whole new level (Channegowda et al., 2015). A schematic framework for V2G technology is shown in Figure 8. Different types of V2G depend on how they are used. For example, there are vehicle-to-home (V2H), vehicle to-vehicle (V2V), vehicle-to-building (V2B) and vehicle-to-grid (V2G). All these types utilize EV battery power to support power network. Table III shows the comparisons between V2G and V2H (Shariff et al., 2019).

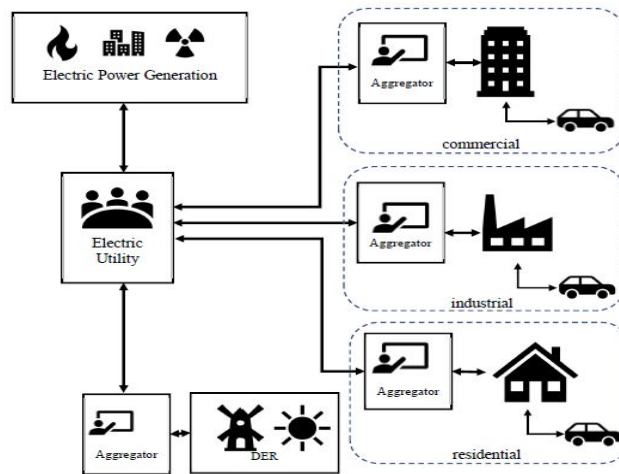


Fig. 8 Schematic framework of V2G (Shariff et al., 2019).

TABLE III
COMPARISON BETWEEN V2G, V2H (SHARIFF ET AL., 2019).

	KEY POINTS	FACTORS	FUNCTIONS
V2G	• A number of GEVs • Less simplicity and more flexibility • Complex Control • Operation at a large scale • Significant transmission losses	• Control and Coordination from the grid operator • Number of aggregators • Battery capacity • Arrival and Departure time • Cost of Electricity • Driving habits of the user	• Reactive power support • Operating with Renewable Sources • Release stored energy back to the grid at peak demands • Grid Ancillary Services
V2H	• Simple Infrastructure • with negligible transmission losses • Easy installment • More simplicity • A single GEV to a single home	• Type of Battery used • Characteristics of Battery Capacity • Charging State • Driving habits of the user • Cost of Electricity	• Acts as a home back-up generator with a controllable load • Sell stored energy back to the grid at peak demand • Cost of Electricity is less at an off-peak time • Used for load shift by cooperating domestic electrical appliances

2.3.2 Management of V2G system

The V2G system is a combination of Optimal Energy Management, Intelligent Energy Resource Management and Battery Management System (Wang & Liang, 2017) (Sousa et al., 2012) (Sousa et al., 2012). EVs have different charging plans (Yilmaz & Krein, 2013) (Mwasilu et al., 2014). In terms of the grid point in the V2G system, EVs' charging should be properly arranged to avoid conventional peak-load periods, hence reducing the impact on power grid. V2G is a new technology and therefore, the research on V2G is at its infancy. Research on V2G is concerned with structure, feasibility analysis and working of each component. Power grid shaving may be done by EVs. Among these are mobile mode and parking mode which are some of the charging schemes for EVs. The strategies for control energy management, as well as algorithms for supervisory control that were used in EVs according to S.Tie-C.Tan (Tie & Tan, 2013).

2.3.2.1 Centralized V2G management

Centralized V2G is a system where energy from electric vehicles is collected in defined areas depending on grid demand to manage charging/discharging strategies in these specific locations (Sekyung et al., 2010). Grids work with charging stations to adjust peak-load for EV charging. Different types of EVs have control strategies provided by F.Salmasi (Salmasi, 2007).

2.3.2.2 Independent V2G management

Centralization cannot manage a mess of EVs scattered everywhere. V2G technology has imbibed smart chargers that are responsible for their costs, reactive power demand and electrical attributes like voltage variations. In their article "Smart charging strategies for plug-in electric vehicles," A.Farghali,-A. Zaki, et al. (Farghali et al., 2016) describes the structure of G2V and V2G charging proposed in the developed world. Power load characteristics differ from one region to another as well as the number of EVs available in each region. Therefore, it is not advisable to organize all scattered EVs under one scheduling system. Based on the hierarchy control, there are three levels within controlling structure of EVs and the grid: scheduling of distribution system, scheduling of transmission system and EV control center itself. The authors D. Liu - Q. Zhong et al. (Liu et al., 2018) presented a concept about modeling and control of a V2G charging station of EVs utilizing synchro converter technology. A technique was proposed by A.Affanni,A.Bellini et al. (Affanni et al., 2005) on manufacturing process for controllable EV charger Each location where this charger is used represents a domestic area, hence its design purposefulness.

2.4 V2G services and advantages

The advantages of V2G technology for Plug-in Hybrid EVs are presented by M. El Chehaly-O. Saadeh et al. (El Chehaly et al., 2009). In various countries in the world, there are several

advantages that can be realized by using V2G technology. There are several benefits to EV owners, charging station and grid and utilities. Some of them include the following.

2.4.1 Ancillary Services

According to Y. Tu- C. L et al. (Tu et al., 2011), ancillary services are provided for. The spinning reserve and the power grid regulation make up two categories of ancillary services. Unidirectional V2G controls the EVs charging rate and thus provides the load only “ancillary services”. In obtaining these ancillary services, a large fleet of EVs is communicated with by the aggregator to achieve the same objective. Power grid regulation maintains frequency for satisfying generation and load demand while spinning reserve has fast response duration for compensating outage in generation which last within 10 minutes.

2.4.2 Active Power Support

The V2G system is where the Grid uses the extra energy of electric vehicles. These are only made possible by a two-way V2G. This service intends to smooth out grid load profile through “peak load shaving” and “load leveling”. Usually, for a small time in a day there is demand. It will be cheaper during peak load to take supply from EVs. This technique can help in minimizing the pressure on power system elements easily. Another advantage is that owners of EV would receive premium prices for electricity. Housing Peak Shaving Algorithm (HPSA) used in houses that have a Plug-in Hybrid EVs was made by H. Turker-A., Hably et al. (Turker et al., 2013).

2.4.3 Backup energy for home

L. Yao- Z. Damiran et al. (Yao et al., 2017) ,F.Fazelpour- M.Vafaeipour et al. (Fazelpour et al., 2014) propose solving the problem of RES with storage through EV fleets. Solar and wind, which are types of renewable energy sources (RES), serve as back-ups or alternatives for V2G systems. Centralized power plants should lower their production if RES generates overcapacity.

2.4.4 Reactive power compensation

C. Silvestre- D.Sousa et al. (Silvestre et al., 2012) discusses the reactive power compensation as a key feature in-built to the V2G technology. Voltage regulation is very essential for the proper functioning of the V2G system. Reactive power compensation provides voltage regulation in the grid. With the help of reactive power, there is an improvement in the power factor. Usually, reactive power compensator draws reactive power to the system. But, in most of the cases, a capacitive reactive power is preferred.

2.5 Challenges behind V2G Technologies

For the implementation of infrastructure for EVs, the current scenario, latest development and challenges should be taken into consideration in relation to charging codes and international standards. However, it has several challenges despite its advantages and services to power grid. V2G does not yet exist in full. Also, there are many hurdles that we have encountered in adopting this technology like economic social technical challenges. The V2G system has a huge effect on the distribution grid (Ready & Grid, 2009).

2.5.1 Degradation of the battery

Battery degradation is a major barrier to EV adoption. The battery system consumes 1/3rd of all EVs costs. A complete electric scooter prototype is presented by A.Affanni- A.Bellini et al. (Affanni et al., 2005) based on battery design . Li-on technology makes up this battery. This electric scooter is efficient. Every battery has specific number of cycles of charging and discharging; after that the efficiency starts reducing with a passage of time while irreversible chemical reaction will decrease its capacity as well as aging effect depend upon DOD, Temperature, Voltage etc., whose values are considered here as independent variables. V2G technology requires a battery with the highest number of charges and discharges. A. Millner (Millner, 2010) has developed a model for the Lithium Ion used in EVs. Table IV is all about charging information for Nissan Leaf and Tesla Models (Lehtola & Zahedi, 2016).

TABLE IV
BATTERY CHARGING TIMES FOR NISSAN LEAF AND TESLA MODELS (LEHTOLA & ZAHEDI, 2016)

Specification	Nissan Leaf	Tesla Model
Battery Capacity (kWh)	24	85
Range (km)	121	426
Slow Charger (kW)	1.8	10
Charge Time (hours)	21	9
Normal Charger (kW)	3.3	20
Charge Time (hours)	7	4.5
Quick Charger (kW)	50	120
Charge Time (1 hours)	0.5	1.25

2.5.2 Investment Cost

The Another major challenge that hinders V2G implementation is its huge investment cost. As per this, the power system for V2G needs to be upgraded accordingly. For efficient V2G implementation, hardware and software infrastructure must be improved significantly or else it will be ineffective. Has one more need for each of participating EVs within the V2G system; bidirectional battery charger should be able to make both operations happen; charging and discharging as well (Kempener et al., 2006). The complex control unit as well as high voltage cable which is bidirectional battery charger consists of these components among others. High-voltage cables require safety measures since they are often needed during charge exchange processes resulting in losses in the energy conversion cycle (Lehtola & Zahedi, 2016).

Conclusion

The research literature has enabled an in-depth comprehension of the latest fashion emanating from electric vehicle industry R&D over the last few years. The literature offers some insight into the current and future needs for quick-charging infrastructure for EV users, which will help to enhance their use by utilities. It also provides a discussion on the challenges that can arise as EVs are integrated into distribution networks without proper management systems, which utility companies must address to minimize negative impacts and transform them into positive ones like

the implementation of smart charging schedules. Building on this foundation of techniques and technologies laid down through such literature, next stage for this study is How can V2G technology be applied within Amman City to benefit both electricity utilities as well as electric vehicle owners?

III. RESEARCH QUESTIONS

1. What is the impact of increasing shares of EVs and PV on the low voltage grid in Amman?
2. What is the impact of controlled charging on the LV grid?
3. What is the impact of vehicle to grid on the LV grid?
4. What are the V2G scenarios can be applied in Amman?
5. How to Transform the traditional grid into a SG?

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