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A Comprehensive Study of Implemented International Standards, Technical Challenges, Impacts and Prospects for Electric Vehicles

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ABSTRACT The impending environmental issues and growing concerns for global energy crises are driving the need for new opportunities and technologies that can meet significantly higher demand for cleaner and sustainable energy systems. This necessitates the development of transportation and power generation systems. The electrification of the transportation system is a promising approach to green the transportation systems and to reduce the issues of climate change. This paper inspects the present status, latest deployment, and challenging issues in the implementation of EVs infrastructural and charging systems in conjunction with several international standards and charging codes. It further analyzes EVs impacts and prospects in society. A complete assessment of charging systems for EVs with battery charging techniques is explained. Moreover, the beneficial and harmful impacts of EVs are categorized and thoroughly reviewed. Remedial measures for harmful impacts are presented and benefits obtained therefrom are highlighted. Bidirectional charging offers the fundamental feature of vehicle to grid technology. In this study, the current challenging issues due to the massive deployment of EVs, as well as upcoming research trends are also presented. It is envisioned that the researchers interested in such area can find this paper valuable and an informative one-stop source.

INDEX TERMS Electric vehicles (EVs), international standards, infrastructure of charging systems, plug-in hybrid electric vehicles (PHEVs), impacts and challenging issues, vehicle to gird (V2G) technology

I. INTRODUCTION

In recent years, air pollution caused by burning fossil fuels in the transportation, industrial and power sectors is becoming a significant challenge for the global environment. The change in climate, incremental energy cost and fossil fuels dependence are considerable issues of the present world. All these challenging concerns are directly linked to above-mentioned three main sectors that heavily utilize fossil fuels. All around the world researchers and governments are paying momentous emphasis to reduce the reliance on the fossil fuels and replace them with clean solutions [1], [2].

Rising concerns about the environment and the call for clean energy has contributed towards the demand for electric vehicles as a mode of transportation. Nowadays, many countries in the world are contributing to achieve certain targets in clean energy environment. To reduce the impact of higher fuel prices and to implement the environmental policies with higher standards, the electric vehicle is an alternative to meet the desire of a green source of transportation with lesser emissions and better fuel economy [3]. The development and deployment of electric vehicle technology is an emerging solution for the afore-mentioned issues with its attractive approach to have higher mileage with reduced emissions. The contribution of world's transportation sector is also increasing the popularity of EVs day by day with the ultimate objective of eliminating harmful emissions. The replacement of internal combustion engines by EVs is a more improved economical approach due to the electrification of major parts in the power and transportation sectors [3,4]. EVs can be broadly classified into Hybrid EVs (HEVs) and Plug-in EVs (PEVs). PEVs are further sub-categorized into Plug-in Hybrid EVs (PHEVs) and Battery EVs. In HEVs, battery cannot be recharged from an external power source in opposition to PEVs [5,6]. In the context of this paper, Plug-in EVs will be incorporated with EVs.

Recently, many research studies have shown that due to green environment, energy-saving feature and easier way of implementation, the technology of EVs hold added benefits over conventional energy-technologies. In urban areas of the world, the EVs are projected to increase substantially and will achieve larger acceptance in the transport market due to their higher efficiency. Many impressive features can be obtained by connecting the EVs to a power grid such as load balancing, reactive power support, active power regulation and sustenance for renewable energy resources [7-9].

In the United States, a target of putting more than two million EVs on the road till the end of 2020 has been established. In this regard, different public policies have been implemented to support electrification in the transportation sector in the US [10-12]. There are many big organizations

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including IEEE, SAE (Society of Automotive Engineers) and IWC (International Working Council), are working to prepare different standards and codes regarding utility interface. To achieve widespread acceptance, EVs are still facing some significant barriers such as: incremental costs, life cycle of batteries, deficiency in the infrastructure of charging the EVs and issues regarding battery chargers. Another major issue is the production of harmful harmonics by EV chargers that have serious impacts on distribution system parameters. This problem can be reduced by using active rectifiers [13-14].

Most of the times, the charging of EVs in domestic areas take place at night in the owner's garage, where electric vehicles will be connected into a suitable outlet for slow charging i.e. Level 1 charging. An upper level charging (Level 2) requires an outlet of 240V and designated as the basic method of charging at public and private facilities. Currently, most of the research addresses Level 2 charging mode, as it can be employed in most of the environments and provide more sufficient power [15-17]. The charging levels 1 and 2 are usually used for single phase solutions. Applications in commercial and public domains preferably use higher charging Level 3 and DC fast charging. Areas near to hotels, shopping malls and in parking lots have chargers of power Levels 2 and 3 [18-20]. A brief comparison of different charging power levels as described by various international standards is summarized in Table I.

The charging system with capability of unidirectional power flow has benefits such as minimum hardware, simplification of interconnection complications, and lesser battery degradation issues [13], [21]. The other charging system with bidirectional power flow has several features including stabilization of power, vehicle to grid technology, and sufficient and controlled conversion of power [22-25]. Inductive or conductive coupling can be achieved by on-board charging systems. A direct connection will be used between the charge inlet and the connector in case of conductively coupled charging systems [26]. For inductive charging systems, power can be transferred wirelessly. In research studies [27,28], the authors discussed the inductive charging systems for two basic charging levels (1 & 2). Inductive charging systems may either be mobile or stationary [29-31]. Higher charging rates can be obtained by designing off-board charging systems.

Various technical studies are being conducted to evaluate the impacts of EVs with special emphasis on the economic, environment, and power grid impact assessments. The economic impacts of EVs can be examined in dual perspective by including the utility power Grid and EV owners. The role of electricity generation mix is considerable to examine the overall economic and environmental analysis of EVs. Negative environmental impacts of EVs will be observed, when charging is completely reliant on fossil fuel-based power units. Based on comprehensive investigation of several technical studies, the considerable issues associated with integration of EVs to power networks are: increase in load profile during peak hours, over loading of power system components, transmission losses, voltage deviations, phase unbalance, harmonics and system stability issues that reduce the power quality and the reliability of the power system.

This paper inspects the present status, latest deployment and challenging issues in implementation of EVs infrastructural and charging systems in conjunction with several international standards and charging codes. It further analyzes EVs impacts and prospects in society. This investigation begins with a summary of charging infrastructural system and different charging power levels for EVs as prescribed by various international standards. This is followed by an extensive analysis of international standards, implemented for development and deployment of EVs. Furthermore, a complete assessment of charging systems for EVs with battery charging techniques is explained. Moreover, the impacts of EV deployment are thoroughly reviewed and analyzed. Finally, the future trends and the challenging issues are addressed. Concluding remarks are drawn in the last section.

II. INFRASTRUCTURAL SYSTEM AND CHARGING POWER LEVELS FOR EVS

Different substantial parameters including impacts on the power grid, cost, equipment, location, total charging time, and the amount of power can be understood with the help of charging infrastructure and various charging power levels. There are many considerable issues that need to be discussed regarding deployment and development of charging infrastructure, and electric vehicle supply equipment (EVSE) such as: 1) Standardization of charging stations, 2) Time and Extent for charging, 3) Demand and Distribution policies, 4) Regulatory procedures.

Cost and requirements for on-board energy storage systems can be reduced with the availability of charging infrastructure. The main components for EVSE are:

- Charging codes and Connectors for vehicle
- Charge stands on public or residential locations
- Various plugs required for attachment
- Power outlets and protective equipment [26], [32]

Two sets of configurations are mostly utilized to have all the above-mentioned equipment: a specific cord set, and a pedestal mounted box set. Basic configurations are changed from country to country and sometimes location may also affect the design based on various significant parameters to consider such as: connections of electrical grid, voltage, frequency and standards regarding transmission systems [33], [34]. Generally, the expected charging time of EVs is an overnight duration at home by different EV owners as described by Electric Power Research Institute (EPRI) [35]. Due to this reason, the primary options will be to utilize the charging equipment of Power Level 1 and Level 2 [15].

The slowest method to perform the charging process of EV is by charging at power level 1. This type of connection might use a standard connector named as J1722 for ac port of EV [36]. Additional infrastructure is not required for home and business locations. At night, minimum off-peak rates are available. According to [37], [38], around 500USD-880USD installation cost is required for Level 1 charging method. Expectedly, this charging level will be combined with EV in near future.

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TABLE I
Types of Charging Power Levels [18], [26]

Types of Power Levels	Location for Charger	Typical Usage	Interface for Energy Supply	Expected Level of Power (P: kW)
SAE STANDARDS: AC and DC Charging				
Level 1: Convenient • **Vac: 230 (EU)** • **Vac: 120 (US)**	**Single Phase** • On-board	➢ Office or Home base charging	➢ Any Convenient Outlet	• **P**: 1.4 (**12A**) • **P**: 1.9 (**20A**)
Level 2: Main • **Vac: 400 (EU)** • **Vac: 240 (US)**	**Single Phase/ Three Phase** • On-board	➢ Publicly & Privately base charging	➢ Electric Vehicle Supply Equipment	➢ **P**: 4 (**17A**) ➢ **P**: 8 (**32A**) ➢ **P**: 19.2 (**80A**)
Level 3: Fast • **Vac: 208-600**	**Three Phase** • Off-Board	➢ Like a filling station, Commercial Point	➢ Electric Vehicle Supply Equipment	• **P**: 50 • **P**: 100
DC Power Level 1 • **Vdc: 200-450**	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• **P:** 40 (**80A**)
DC Power Level 2 • **Vdc: 200-450**	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• **P:** 90 (**200A**)
DC Power Level 3 • **Vdc: 200-600**	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• **P:** 240 (**400A**)
IEC STANDARDS: AC and DC Charging				
AC Power Level 1	**Single Phase** • On-board	➢ Office or Home base charging	➢ Any Convenient Outlet	• **P:** 4-7.5 (**16A**)
AC Power Level 2	**Single Phase/ Three Phase** • On-board	➢ Publicly & Privately base charging	➢ Electric Vehicle Supply Equipment	• **P:** 8-15 (**32A**)
AC Power Level 3	**Three Phase** • On-board	➢ Like a filling station, Commercial Point	➢ Electric Vehicle Supply Equipment	• **P:** 60-120 (**250A**)
DC Rapid Charging	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• **P:** 1000-2000 (**400A**)
CHAdeMo Charging Standard				
DC Rapid Charging	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• 62.5 (**125A**)

The main and basic method which can provide dedicated services at public and private locations is via charging power level 2. To have lesser power electronics, on-board facility is provided at this charging power level. At household and public locations, the charging level requires a proper equipment with a connection installation. As most of the houses have availability of 240V service, the devices associated with this power level can charge the vehicle battery overnight. The Level 2 charging method is preferable due to fast charging time and convenience of standardized vehicle-to-charger connection. According to technical study [39], around 1000 USD-3000 USD installation cost is needed for Level 2 charging process and cost of 2150 USD for residential unit infrastructure [38]. SAE's J1772 has a combo connector providing a connection for AC on the top side and the lower side have a two-pin dc connector. It can provide both ac as well as dc fast charging.

The power Level 3 charging process is used commercially and provides the fastest charging time just in less than an hour. It is comparable with petrol stations and can be installed in highways rest points and urban refueling stations. To supply regulated AC-DC conversion, an off-board charger is needed. Charging power level 3 is not suitable for residential locations.

For DC plugs and hardware, different standards are in improvement stages. A new standard corresponding to DC fast charging called "CHADeMO" from Japanese national protocol is getting recognition much rapidly throughout the world [40]. This standard is designed to increase the deployment of EVs and to address concerns regarding optimal mileage among EV users [41]. This standard has the capability to recharge the EV within 30 min up to 80% state of charge via optimal DC charging power [42]. However, the major concerns are the executing cost that is between USD 30000 and USD 160000 [43,44] and the maintenance cost of this charging power level.

The SAE Standard in [26] suggested that the EVSE of the first two power charging levels (Level 1&2) must be accommodated on the vehicle; however, the EVSE of power level 3 should be outside the vehicle. To realize the fast charging at commercial points, the charging power Levels 2 and 3 should be employed at public stations [45]. Lower charging levels (1 and 2) have lesser impact on peak demand of the power grid as compared to higher rapid charging which can quickly overload all the distribution equipment [46]. The charging power Levels 2 and 3 have following considerable impacts on distribution systems:

- Reliability of a system
- Deviations in voltage
- Power losses/Transformer Losses
- Increase in peak demand

- Thermal loading
- Transformer life
- Efficiency and security
- Economy of developing grids [47,48].

To alleviate the impacts of charging performed by high power charging levels, the coordinated controlled charging scheme should be employed [49]. To have integration of larger number of EVs, proper control of charging scenarios and appropriate communication is needed. The implementation of charging infrastructure with EVSE arrangements is shown in figure 1 [33].

III. INTERNATIONAL STANDARDS AND CHARGING CODES FOR ELECTRIC VEHICLES

The successful employment, expansion and appropriate operation of EVs in near future is directly linked with the establishment of new international standards and charging codes, suitable infrastructure and related equipment, and software at public and private locations that should be user-friendly.

Extensive range of technical issues of EVs can be analyzed by the implemented international standards and the safety codes. There is a correlation between the hardware standards of electric vehicles and cost of charging infrastructure [50,51]. In future, there are some significant possibilities corresponding to these standards and charging codes of EVs that makes the infrastructure of charging costlier and more complex in comparison with existing electrical infrastructure.

In the National Electrical code [52], it is mentioned that, (as per article 625-18) for the charging Levels 2 and 3, the cables and connectors should be de-energized before they are plugged in to the vehicle. This will introduce an extra cost to EVSE. Generally, the manufacturers of EVs put an interlock which controls the vehicle from being driven at the time of charging. Currently, there are many workgroups from international organizations that have been working for standards and charging codes of EVs such as:

A. Society for Automobile Engineers (SAE) [53]

- J1772: EV conductive connector/charging method
- J2894: Issues of power quality
- J2836/2847/2931: Communication purposes [10]
- J1773: Inductive coupled charging
- J2293: For energy transfer systems to find the requirements for EVs and EVSE

B. International Energy Agency (IEA)

C. National Fire Protection Association (NFPA)

- NFPA 70: Safety management
- NEC 625/626: Charging systems for EVs
- NFPA 70E: For safety
- NFPA 70B: Maintenance for electrical equipment

D. International Working Council (IWC)

E. Institute of Electrical and Electronic Engineering (IEEE)

- IEEE 2030.1.1: Quick DC charging for EVs
- IEEE P2690: Charging network management, Vehicle authorization
- IEEE P1809: Electric transportation guide
- IEEE 1547: Interconnecting electric system with distributed resources/Tie Grid
- IEEE 1901: Provide data rate while vehicles charged overnight.
- IEEE P2030: Interoperability of smart grid

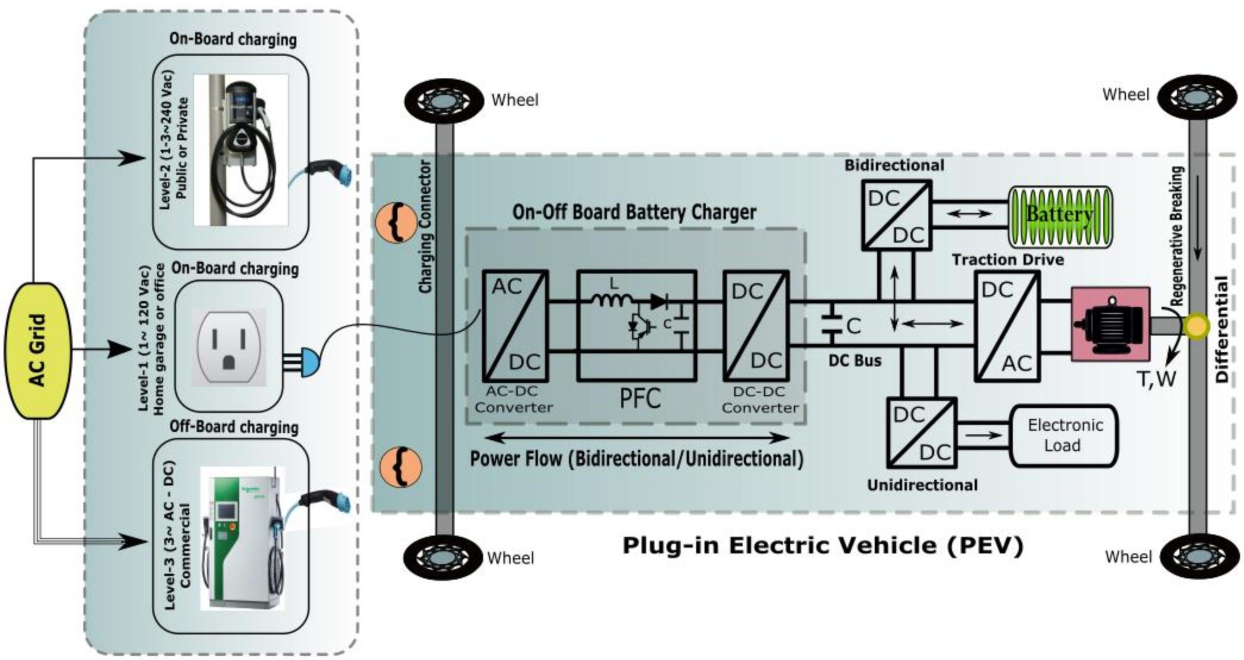

Figure 1:EV Charging Infrastructure with EVSE Arrangements [33]

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F. International Electromechanical Commission (IEC)

- IEC-1000-3-6: Issues of power quality
- IEC TC 69: Regarding infrastructure of charging and safety requirements
- IEC TC 64: Electrical installation, electric shock protection
- IEC TC 21: Regarding battery management

G. Underwriters Laboratories Inc.

- UL 2231: Safety Purposes
- UL 2594/2251,2201: EVSE

H. Deutsches Institut fur Normung

- DIN 43538: Systems for batteries

I. International Organization for Standardization

- ISO 6469-1:2009: Used for on-board rechargeable energy storage systems
- ISO/CD 6469-3.3: Safety specifications

J. Japan Electric Vehicle Association

- JEVS C601: EVs charging plugs
- JEVS D701: Batteries
- JEVS G101-109: Fast Charging

However, there are several groups working on the standards and codes of EVs and possibility of overlap exists. Figure 2 [54-57] presents significant implemented international standards required for deployment of different EVs.

1) ISOLATION REQUIREMENTS AND SAFETY PRECAUTIONS FOR EVs CHARGERS

The requirement for isolation is essential for all major components of EVs such as: dc/dc converters, electric motor driving inverter, high voltage battery, and the charging module which is connected to the power grid. Consequently, the main equipment which exists between the EVSE and the existing grid system is the power transformer. During the charging process, the body of EV must be earthed in case of both on-board and off-board chargers. Isolation for battery is required; and isolation monitoring must be included, when electrical separation is not present for the EV charger [58], [59].

Typically, DC-DC converters which are non-isolated have significant benefits including the lower cost, higher efficiency, simple arrangement, size, weight, high reliability, etc. Nevertheless, there is no galvanic isolation present for low frequency methods at the DC/DC converter stage. Consequently, a line-frequency transformer is required which provides the isolation galvanically between the grid and the batteries. There must be an increase in the operating switching frequency to have a reduction in the magnetic materials and decrease in the volume requirements [33]. There are certain reasons that cause battery chargers to be used often at off-board locations such as: an increase in size, higher weight due to converter cooling system, inductors and capacitors required, and isolation transformer. High frequency transformers are used to provide galvanic isolation in the dc/dc converter stage for larger frequency arrangements. The design of transformers plays a vital role to have a reduction in various significant parameters including size, losses and cost. The main benefits and problems

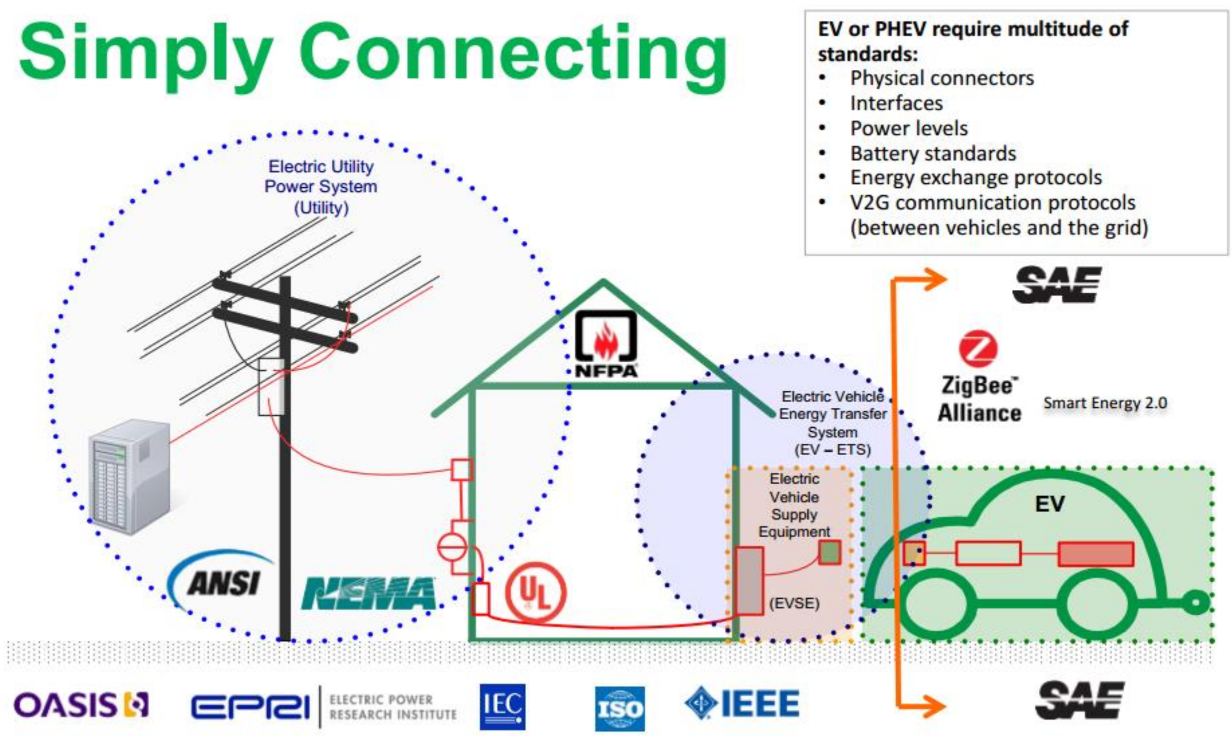

Figure 2: Implemented International Standards for EVs [26], [55-57]

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(represented below by ○) in providing isolation by high frequency transformers are:

- Better control by regulating voltage
- Compactness
- Protection for load apparatus
- Beneficial for variable applications

○ High snubber losses
○ Impact on soft switching operation for partial load conditions

To achieve appropriate power requirements for Level 2 charging apparatus, the existing electricity voltage level must be stepped down to a level which is suitable for the Level 2 charging equipment i.e. 208 to 240V. If this is not possible, installation of isolation transformers can perform the step-down operation for Level 2 charging process and step-up operation for Level 3 charging schemes. The cost of isolation transformer is between 7200$ to 8500$ [33].

In comparison with the on-board isolated chargers which have higher cost issues; the galvanic isolation is a preferred option for charging circuits due to the safety reasons. If available traction hardware is utilized i.e. inverter for the charging circuit and traction motor; major issues such as: added weight and space of charger and higher cost can be resolved. Various configurations are being studied with major emphasis on the electric machines with an added set of windings to solve the issues regarding the isolation. The main concern of a system is to lessen the issues of electric shock for safety of owner during the charging process of EVs, either in case for isolated or grounded circuits are discussed in personnel protection system standard. The implemented standards and technical codes only emphasizing on the safety concerns of EVs are presented in Table II.

IV. CHARGING SYSTEMS AND BATTERY CHARGING TECHNIQUES

In several types of EVs including PHEVs, the charging process of battery packs is completed externally from a power network through a device called battery charger. The basic arrangement of battery chargers is shown in figure 3. The battery of an EV will be charged by a charger through energy transformation to the battery with the controlling and processing of the electric current. The basic need of a charger in the charging process is due to the availability of alternating current (AC) from the power grid, while an EV battery required the direct current (DC). The design of an EV charger is such that it incorporates the rectifier to have appropriate DC power level for charging the EV battery. Usually, the EV charger is built as an AC/DC converter. In case of fast charging, there is an addition of DC/DC converter in EV charger to have better energy conversion.

A. EV CHARGING SYSTEMS

The EVs charging systems can be classified according to the energy transfer mode such as: Conductive charging systems, Inductive charging systems, and Battery swapping networks. The conductive systems need a physical linkage between the supply network and the EV. In the conductive mode, the energy is transferred using a direct contact via a cable between the connector of EV and the charging inlet point. This charging system utilizes a cable conductor, which can be taken from outlet of any charging power level (Level 1, 2 and charging station Level 3), for establishing a power connection to electronic equipment, to make the possible flow of energy. Conductive charging systems are simpler and more efficient. They can be used for on-board chargers for slow charging techniques which are implemented inside the EVs, and off-board chargers for fast charging techniques. Conductive charging systems can be realized for currently available vehicles such as: Nissan Leaf, Chevrolet Volt, Mitsubishi i-MiEV and Tesla Roadster [60].

On the other hand, an emerging concept of inductive charging system, also known as wireless charging system needs no physical linkage between the power network and the EV. The electromagnetic field is used to transfer the power to EV battery.

TABLE II
Isolation and Safety Standards for EVs

Technical code of various standards	Details
SAE J-2929	This standard is related to safety of propulsion battery system.
SAE J-2910	This standard deal with the electrical safety of buses and test for hybrid electric trucks
SAE J-2344	Define rules for EV safety
SAE J-2464	Standard defines the safety rules for recharge energy storage systems(RESS).
ISO 6469-1: 2009 (IEC)	Standard is related to electrically propelled road vehicles, on-board RESS, inside and outside protection of a person
ISO 6469-2: 2009 (IEC)	Safe operation of EVs, provide protection against inside failures.
ISO 6469-2: 2001 (IEC)	Electrical hazard protection.
IEC TC 69/64	EV infrastructure safety, electrical installation, electric shock protection.
NFPA 70/70E	Standards related to the workplace safety, charging system safety, branch circuit protection.
UL 2202	Standard is related to the protection of a charging system
UL 2231	This standard deal with the protection of supply circuits
UL 225a	It provides rules of protection regarding couplers, plugs and receptacles.
DIN V VDE V 0510-11	Provides safety regulations for battery installation and secondary batteries

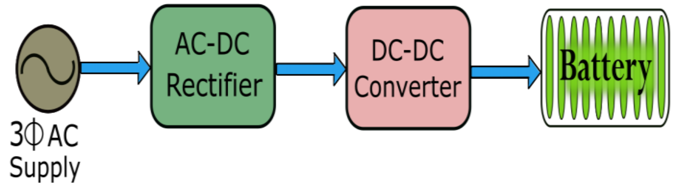

Figure 3: Basic Configuration of Battery Charger

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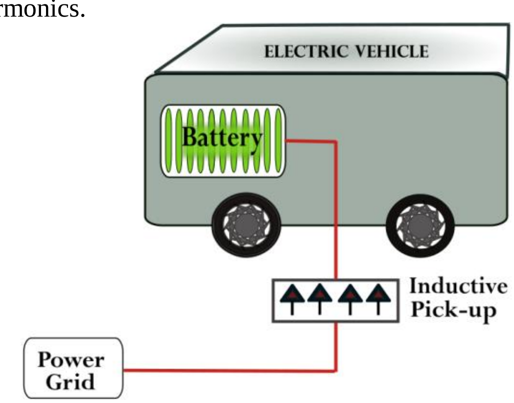
The charging stations and the EVs have induction coils installed and electromagnetism is used to transfer power [61], [62]. The charging power levels (1 and 2) have been explored for wireless charging. The significant benefits that can be achieved by employing this concept are: 1) User convenience, 2) Electrical safety in all weather conditions, 3) Durability, 4) No cords and cables.

Nowadays, there is a possibility to incorporate charging strips into the main highways, which allows charging while driving. Therefore, the concept can reduce the need for fast charging infrastructure. However, the technology is new and immature, so it suffers from some limitations. The drawbacks include size, cost, power density, power loss, lower efficiency and complex infrastructure. Figure 4(a) represents the basic arrangement of an inductive charging.

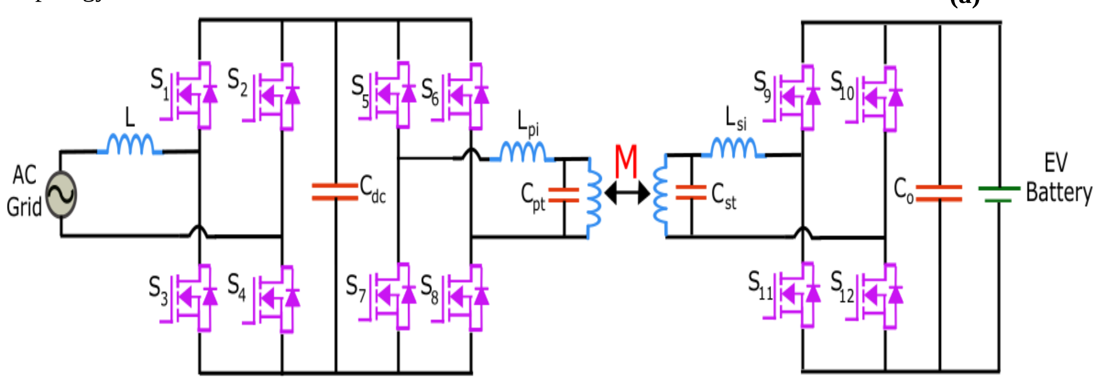
The contactless converter configurations have been realized for V2G applications, which utilize the concept of inductive charging or wireless energy transfer with loosely coupled transformers by resonant phenomena. By using these converter topologies, the charging and discharging operating modes are much convenient and flexible.

The high-frequency isolated DC-DC converter with inductive power transfer (IPT) is shown in figure 4(b) [63]. It is a two-stage contactless converter configuration with 1-phase PWM converter at the first stage. The soft-switching ZVS turn-on of the power switches (S1-S8) is achieved by LCL parallel resonant tank networks in the second stage (DC-DC) of the converter topology.

The angular difference in between the primary and secondary side voltages of the transformer is used to control the output power. However, the transmission efficiency of the second stage is around 85% which is not up to the efficiency criteria of V2G applications. In [64,65], the bidirectional topology based on matrix converter with IPT is proposed as shown in figure 4(c). The converter has four bidirectional power switches (S1-S4). The single stage power conversion is performed in this converter topology, thus eliminating the need for dc linkage to enhance the overall efficiency of the system as compared to converter topology in [63]. As only a single DC capacitor is used by the converter, so it has the added benefit of small size and lower cost. However, the current waveforms of the converter topology at grid side contains higher contents of the harmonics.



(a)



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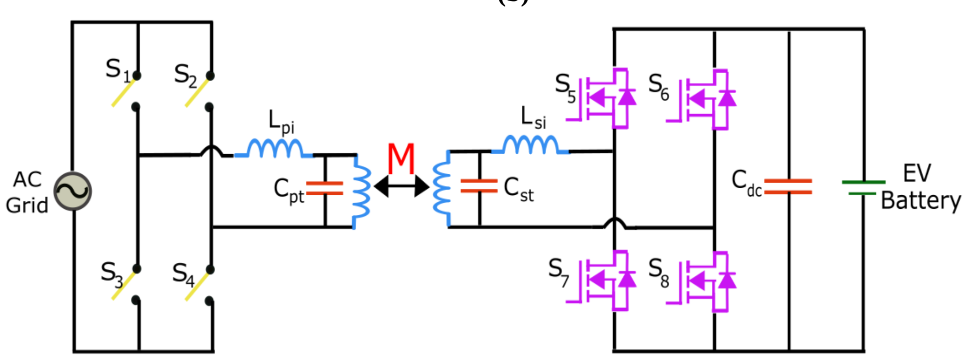

(c)

Figure 4: (a) Arrangement of Inductive Charging, (b) High Frequency Isolated DC-DC Converter with IPT, (c) Bidirectional Converter Topology Based on Matrix Converter with IPT

The third major type of charging system is based on battery swapping technique. This is a kind of method by which owners of EVs can swap partially or completely discharged batteries with fully charged ones. The process of battery swapping occurs at specific places called battery swapping stations (BSS). Numerous benefits can be achieved from the BSSs when the collection of batteries and management is performed at centralized locations, including: enhancement of battery life, less consumption of time and relatively lower costs of management. Currently, TESLA the market leader in transportation sector swaps the battery of EV in just 90 seconds [66]. Battery swapping provides a method to reduce or prevent load demand peaks caused by EVs that can save a substantial amount of money [67]. However, BSSs suffer from several limitations such as: higher initial investment cost and large and huge space for construction process of BSSs. The current BMS are not up to the standard criterion to confirm with battery safety [68]. China is on the top of list for larger number of BSSs and charging points in the world [69].

B. BATTERY CHARGING METHODS FOR EVS

The rechargeable state of the battery is viewed as the major energy resource for charging the EVs. The substantial enhancement in the field of battery technology is one major reason for the recent extensive deployment of EVs. Currently, the main technology of batteries as energy storage has moved from lead-acid batteries to lithium-ion batteries. Some researchers are also working on high energy density batteries for different applications of EVs such as lithium-sulfur batteries [70]. Various charging methods are considered for charging the EVs batteries, which includes:

- Constant Voltage (CV)
- Constant Current (CC)
- Constant Power (CP)
- Taper and Float Charging
- Trickle Current (TC)

Recently, another advance method related to battery charging technology contains the combination of the afore-mentioned methods for better control of battery charging; thus, resulting in a new method named as CC-CV charging method. Some other methods for fast charging battery applications of EVs are pulse and reflex or negative pulse charging methods [71,72].

1) SLOW CHARGING:

The CC charging is a simple charging method which is used to sustain the flow of charging current towards the battery by changing the charging voltage. The process is continued till the battery voltage moves up to a pre-set value. This method injects a lower current level to the discharge battery. Usually, the level of current is defined as 10% of the rated maximum capacity of the battery. Nickel-metal hydrate batteries and nickel-cadmium batteries are the best candidates for CC charging method [72]. However, the overcharging of battery may cause the gassing and overheating issues. Serious damage to the battery pack may occur due to continuous over or under charging scenarios. Thus, an adequate control is required for battery charging regarding current and voltage profiles (CC, CV and their combinations) [71,73]. In CC charging method, during the start of the charging operation, the battery systems utilize much higher power. If the higher power is not appropriately managed, the life of the battery pack might be reduced due to a higher rate of current injection under lower charging condition. On the other hand, in CV charging method, the constant charging voltage is applied by varying the charging current. The process is sustained till the battery charging current reduces to almost zero. The issue of drawing excessive power can be avoided in CV charging method. Moreover, the risk of overcharging the battery is avoided due to less amount of current drawn during the charging state. However, charging time is much extended to avoid the issues of CC charging method. The CP charging method is just to charge the battery at a constant amount of power. The method of taper charging is performed by using a constant unregulated source of voltage; and due to high cell voltage because of higher charging rate, the charging current decreases in an uncontrolled manner. This may cause severe damage to battery pack through overcharging [71-73]. In contrast, the method of float charging employs the CV charging technique under the upper boundary of the battery. This method is appropriate for lead-acid batteries and usually employed for emergency power back-up situations. The method of trickle current charging is employed to charge the EV battery with a lower value of current to overcome the battery discharge [71-73].

2) FAST CHARGING:

To avoid the afore-mentioned issues in different charging methods and to have faster and safe charging of EVs batteries, the authors in [74] combine the constant current and voltage (CC and CV) charging methods by illustrating current and voltage charging profiles as in figure 5(a). The charging profiles are divided into three main sections: initially, there is a pre-charging mode in the first section, followed by CC charging mode in the second section and CV charging mode in the last section. In the pre-charge mode, to increase the level of battery voltage to a specific limit, the current is increased in small stages. The specific limit is referred as a constant current threshold, as mentioned in figure 5(a). This is performed to certify that power injected in a controlled manner during the starting period and thus avoiding the battery damage. Beyond the threshold limit, the higher value of constant current is provided by controlling the charger. Therefore, the battery charging process is completed quickly and accomplish 80% of its State of charge (SOC) level. At this stage, to restrict the level of current and protect the battery from damage due to overcharging, the battery charger is pushed to enter into the CV charging mode. In this mode, the process of battery charging is performed with a reduced level of current, whereas maintaining the constant charging voltage [71-74].

The CC-CV battery charging method is the best suitable option to quickly charge Li-ion batteries as these batteries have high energy densities and more power. The CC-CV charging method is employed for most of the chargers used commercially. The benefits which can be achieved by implementing the CC-

CV charging method are: 1) Limited charging current through battery, 2) Limited charging voltage, 3) Controlled injected power, 4) Proper utilization of battery controller, 5) Protection of battery from over-voltages, 6) Reduce thermal stress, 7) Fast Charging.

In another study [75], a method to enhance the performance and life of EV battery is proposed. The factor which has a significant impact on the battery life and the performance is the variation in temperature of the battery. Small rest stages are included in the proposed methodology to lessen the battery temperature. The study demonstrates that through the proposed strategy, the battery degradation is decreased to a reasonable level of 14% in comparison with CC-CV charging method. As a result, the battery life and performance are improved by 17%. However, the total charging period of EV battery is increased due to inclusion of rest stages. To improve the charge capacity of a battery and to reduce the cell diversity/cell imbalance problem, the authors in [76] proposed the reconfiguration-assisted charging (RAC) for large scale Li-ion battery systems utilized for EVs. Initially, the cells in the battery system are classified depending on their real-time voltages, and then the charging method CC-CV is implemented in a categorized way. RAC is evaluated based on simulations and experimental setup. The obtained results verified that the proposed methodology increases the charge capacity of battery cells by almost 25%.

In numerous studies [77-79], the method of pulse current (PC) charging is implemented to charge the batteries of EVs quickly. This charging method performs the EV battery charging by utilizing the charge pulses in each second to flow the charge current into the battery. Consequently, the precision in controlling the pulses has a significant importance. One interesting fact about the PC charging method is that the chemical action of the battery is stabilized by introducing the small rest gaps of around 20-30 milliseconds among charging pulses as mentioned in figure 5 (b) [71].

The purpose of rest gaps is to match the process speed of chemical reaction and the charging process. Thus, gas formation is reduced at the electrode surface. In [80], a new battery charging technique based on duty-varied voltage pulse-charging technique is implemented to enhance the battery charging capability. The implemented strategy did not utilize the constant pulse width, it detects and employs the appropriate and varied charge pulse to improve the battery charging speed and increase the charge efficiency. The experimental results of the proposed charging technique showed that the battery charging speed and the charging efficiency are improved by approximately 14% and 3.4% in comparison with typical CC-CV charging method.

On the other hand, the negative pulse-charging method is a complementary charging technique. This technique implements a very small discharging pulse during the rest gaps of pulse charging method as shown in figure 5(b). The purpose of this process is to depolarize the EV charging battery and to avoid gas bubbles on the electrode surface that form during the pulse charging state. This charging strategy is utilized to improve the complete charging procedure and increase the life of EV battery.

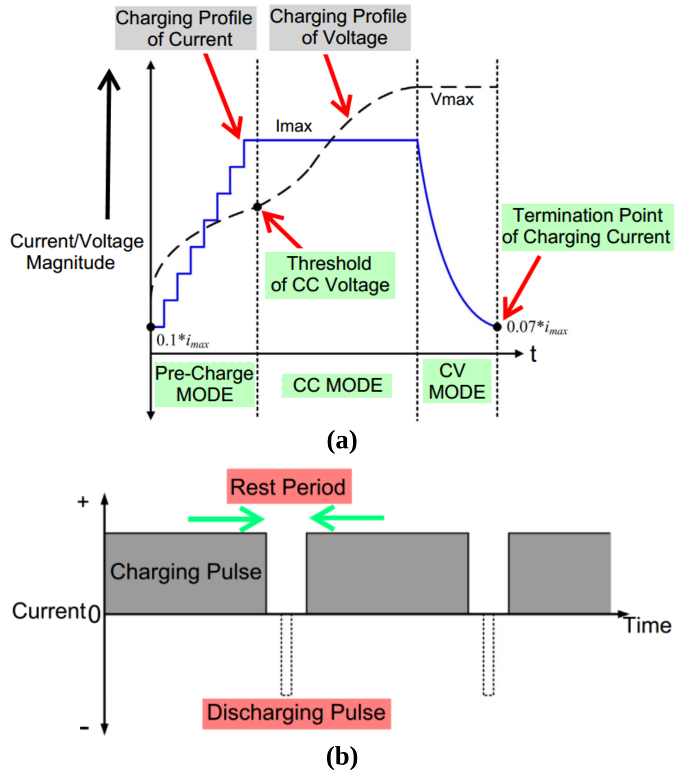

Figure 5: (a) CC and CV Charging Profiles of a EV Battery Pack, (b) Operation of Pulse-Charging method

In [77], the authors implemented the PC charging method based on controlling the duty cycle and optimal frequency, to increase and improve the battery charging process. The results of implemented strategy revealed that charging speed is improved by two times faster in comparison with the CC-CV charging method and efficiency is 52% more in contrast with CC fast charging technique. The PC charging method proposed in [78] is based on hybrid sinusoidal PC charging technique for li-ion batteries. The simulated and experimental results of the implemented technique verified that the battery charging capability and energy transfer efficiency are improved in comparison to standard PC charging technique. In [79], the authors employed a charging technique based on positive and negative pulse frequency current controlling method. The implemented strategy is utilized to reduce the charging time of an EV in a rapid charging station. The results of the implemented technique showed that battery charging time is improved from 20% SOC to 80% SOC (4 min less) and temperature rise is reduced (1C^o) in contrast with the standard CC-CV charging method. In [81], the authors discussed a network consisting of fast charging stations (FCS) that can provide higher quality of services (QoS) to EV drivers to enhance the EV penetration levels. Major problems regarding the effective operation of a network containing FCS are elaborated with respect to stability of a power grid and satisfaction of EV customers [81]. A general architectural framework of a charging station which has the capability to maintain the stability of a power network is proposed in [82].

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The network can provide higher quality of services to EV customers as well. The performance of a charging station is analyzed based on several parameters including the size of energy storage, traffic characteristics and cost factors [82]. In [83], the authors pointed out the basic need of charging stations at public locations for widespread adoption of EVs. Detail insights are provided to design a modern charging station based on renewable resources and energy storage units. In [84], the authors demonstrated that decisions based on appropriate charging location has a critical influence on the adoption rate of EVs. Hierarchical optimal framework is proposed to figure out the suitable location of fast charging stations in an urban area. The results achieved from the study showed that the implemented model boost-up the overall performance of the system and improvised services to the EV customers.

For large scale deployment of EVs, the battery charging time carries a significant importance for a battery management system. In several research studies, the basic CC-CV charging method to charge the EV battery is improved in the battery charging capability and total charging time. For the same reason, the PC charging technique is implemented in various technical studies for improvement. However, the current charging system of the battery still suffers from various technical issues. Consequently, more research work is required with different variations to provide much better solutions for enhancement in battery charging techniques.

V. IMPACT ASSESSMENT OF EVS

As far as current transport market conditions are realized, the high growth rate of EVs is projected to have huge penetration in distribution networks in the coming future. The current power networks may suffer from additional loads due to extensive charging consumption of EVs, which are adversely affecting the existing conventional distribution grids. On the other hand, the extensive utilization of EVs with advanced technologies has favorable economic and environmental friendly impacts. The EVs are not only capable of decreasing greenhouse gas emissions but many impressive features can be obtained by connecting the EVs to a power grid such as balancing of load, reactive power support, active power regulation and sustenance for renewable energy resources [54,85,86]. As a result, EVs play a vital role in green energy environment. It is significantly important to examine the economic, environmental and power grid needs and impacts introduced by the deployment of electric vehicles in the modern transportation system. Extensive research has been done to study the impacts of EV in these three major areas as shown in figure 6[53]. Some of the findings have been discussed categorically in the following sections.

A. ECONOMIC IMPACT ASSESSMENT OF EVS:

The economic impacts of EVs can be examined in a dual perspective by including the utility power Grid and EV owners [87]. From the power grid point of view, EVs add significant load to counter charging needs for daily transportation. The expected load will introduce additional power generation cost in terms of fuel and generation capacity [88].

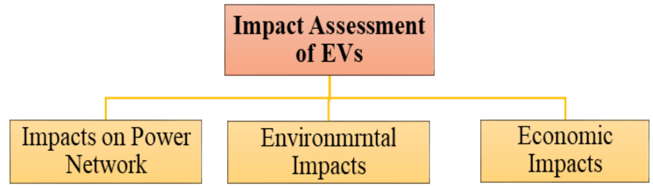

Figure 6: Categories of EVs Impacts

The Power transfer losses will increase, which can be catered by introducing efficient charging strategies [89]. Up to 60% savings in the system cost and reduction in peak demand can be realized through control charging of EVs [90]. In [91], the authors figured out that, savings up to 227$ per year per vehicle can be achieved with smart charging strategy as compared to simple charging method. Additional cost control and reduced peak demand can be achieved through RES integration, specifically from wind energy. 200$ to 300$ per year per EV savings in power network cost can be obtained from EV fleet as proposed in [92,93]. In [94], the authors demonstrated that domestic customers can get various financial incentives from demand response programs. The significant benefits which can be achieved from these programs are to counterbalance the harmful impacts that arise from uncontrolled charging scenarios and reduce the EV charging cost to support EV customers. The capacity of power network to control peak demand with various levels of EV penetration was studied in [95]. In [96], the authors investigated that the distribution grid can manage well up to 16% penetration of EVs with latest energy prices. The economy based charging impacts of EVs are discussed in [97]. Different research studies [98-100] demonstrate that power system will suffer from severe power losses during the charging process of EVs with various levels of penetration. Power losses due to EVs charging are considered as an economic issue as it has significant impacts on distribution grid. The life span of a transformer will be reduced by excessive uncontrolled charging of EVs. For instance, 15KVA and 25KVA transformers suffered breakdowns and burn outs in Los-Angeles and Vermont due to uncontrolled charging of EVs. Thus, improvement in charging methodologies and charging infrastructure of EVs needs great attention to improve the economic aspect of the power network.

From the owner's point of view, several benefits can be achieved from EVs, such as: lower operating costs due to high efficiency of electric motors and comparatively lower cost of electricity [101]. The efficiency of EV technology (60-70%) is higher in comparison with ICE vehicles [102]. In contrast, higher capital cost of EVs due to expensive battery technology in comparison with conventional ICE vehicles gives it a setback. A term named as "EV payback period" is introduced to estimate investment return time period of EVs [103]. Initial cost control can be achieved with mass production of EVs, new charging strategies and infrastructure, and introducing energy trading and incentives/reward-based policies [104-106].

A study [107] proposed the deployment of optimal recharging infrastructure with battery switching and quick charging possibilities for long distance travel considering large EV market presence. The study even with moderate EV share raised a positive flag for: 1) tax redistribution, 2) operators and user's mutual benefits and, 3) external gas reduction. The outcome of the study showed that the battery swapping technology is more favorable choice than quick charging for long distance travel.

The ongoing advancement in battery management systems and battery storage technology will enhance the economic lifecycle of batteries. The comparative economic analysis of EVs can be achieved by a well-defined criterion based on high efficiency of electric motors, improved BMS and battery storage technologies. The economy of utility gird and profit for EVs owners based on electrification of transportation system will greatly enhance by realizing the V2G technology [54]. The power grid can increase its economy by implementing the smart charging infrastructure with smart strategies of charging. CO_2 emissions and consumptions of fossil fuel will drastically reduce with large scale deployment of EVs.

The power network needs to be updated with advanced infrastructure and more generation capacity to meet the higher load demand of EVs and EV customers must pay more for the initial purchase. Increase in generation capacity, fuel cost and high initial cost for owners shows negative economic impact of EVs. However, several research studies conclude that with the introduction of improved charging strategies and advanced infrastructure, electricity policies, trade incentives, and different reward policies, EV development and deployment can be gainful in both perspectives.

B. *ENVIRONMENTAL IMPACT ASSESSMENT OF EVS:*

The drastic changes in global climate conditions have forced governments to pay more attention to EVs, as contribution of the transport sector in carbon emissions is taken as the second highest. The electrification of transportation sector can be achieved with massive deployment of EVs in urban areas. This transformation of transportation sector provides a friendly environment, which is based on reduced levels of CO_2 emissions. The $C0_2$ emissions will be reduced up to 1-6% till 2025 and 3-28% till the end of 2030 as discussed in [53], [108]. This is achieved by integration of EVs to power networks. Moreover, massive incorporation of EVs within V2G environment further contributes to clean and safe energy society. The dependency on fossil fuels can be reduced by advancements in EV technology to have a green environment [108]. In [109], the authors described the environmental impacts of EVs for Denmark city and discussed reduction in CO_2 gas emissions up to 85%. Several environmental benefits can be achieved by integration of EVs with RES. The V2G technology plays a vital role in clean energy environment [110]. Reduction in CO_2 gas emissions have a significant contribution to evaluate the environmental impacts of EVs. The highly efficient electric motors in EVs plays their part to have less CO_2 gas release as compared to ICE vehicles. The environmental impacts of EV for various countries are discussed in [87].

Currently, the load demand of EVs is fulfilled by the power grids instead of using conventional fuel-based methods, therefore reducing CO_2 emissions. Furthermore, the addition of power networks based on alternative RES, which are used for EV charging, further contribute towards fewer pollutant emissions [111]. Various countries are putting much effort by introducing RES based charging stations to have a green environment [112,113]. With increasing penetration of EVs, potential environmental impacts of EVs are being analyzed, and claimed that the EV technology is environmental friendly with zero GHG emission. It is also noticeable that increase in electricity demand by EV charging will indirectly add GHG emissions through generating stations by supplying the additional power. To evaluate the environmental impact performance of EVs in comparison with conventional ICE vehicles, a term "Well-to-Wheels" is introduced which take into account the lifetime emissions including exhaust pipe emissions, material, and energy utilized to power the vehicle. Minimum Well-to-Wheels emissions are suggested by various research studies for EVs [111,114,115].

To analyze the contaminants per km and CO_2 gas emission concerning EVs, the authors in [116] propose a strategy that comprises whole scenarios of consumption and production of electricity from various resources for all events of recharging, levels of emission and various factors. This study describes several benefits of EVs in relation to various kinds of gas emissions that include CO_2, nitrogen oxide, and carbon mono oxide emissions; and in the end, concludes with a lower well-to-wheels release for EVs. In contrast, the authors in [117] figured out the environmental impacts of EVs based on life cycle evaluation strategy which incorporates the well-to-wheels stages and electricity production mix and suggests that EVs are the vehicles with least intensity of carbon gas emission. A comprehensive model was developed in [118] to investigate the impacts of GHG emissions for large scale deployment of EVs in Los Angeles. The environmental impacts for two different years with a gap of a decade were analyzed. The study results of the former year found that due to electricity production from coal resources, even the off-peak charging hours of EVs have higher GHG emissions impact on the environment. On the other hand, evaluation results of the latter year showed that carbon emission impact was greatly lowered for off-peak charging scenarios as compared to previous year based on no power generation from coal. However, massive integration of EVs to power networks creates substantial operational issues for utility operators. In study [119], the authors demonstrated that implementation of EVs has a vital role for mitigation of CO_2 gas even without the participation of wind energy for electricity generation.

In different cities of US, the fossil fuel plants utilized roughly for 65% of the generation capacity, even with simple charging strategy of EVs, the CO_2 emission level is reduced up to 10% in comparison with gasoline vehicles as proposed in [120]. In another study [121], the CO_2 emission impacts are analyzed for three main regions of China considering various scenarios of EVs penetration. In every situation, the CO_2 emission is reduced for all developed regions of China, even though up to 79% of the electricity production capacity is based on the contribution of coal power plants. The study in [122] is based on large scale deployment impacts of EVs in an urban culture. The environmental impact of EVs is evaluated on three rates of deployment and in each case mitigation in emissions of NO and NO_2 gases were found. The evaluated results demonstrated that up to 50% replacement of normal vehicles with EVS reduces the emission of NO gas by 15% and NO_2 gas by 5.5% respectively.

However, the charging of EVs through conventional power plants including coal, natural gas and various fuel generating units with significant emission of pollutants may cause a comparable increase in "Wells-to-Wheels" of EVs than ICE vehicles. A mixed coal and natural gas generating unit in Texas has suggested an increase in emission from EVs compared to ICE vehicles [123]. Similarly, in a coal fired generating unit in Ohio, a comparison between EVs and ICE vehicles revealed the increase in SO_2 and NOx emissions by EV charging and a significant reduction up to 24% in CO_2 emissions by employing EVs [124]. In [125], authors examined the higher CO_2 gas emissions with a massive integration of EVs to the power networks due to electricity production from gas or coal power plants. The recycling process of dead li-ion batteries can increase the pollutants in the groundwater because only very few organizations are capable to perform the complete recycling process of these batteries [126].

The potential harmful environmental impacts are explained in a study [127] of lithium-ion batteries for EVs conducted by the Environment Protection Agency (EPA) and U.S. Department of Energy. The study suggested that the batteries with nickel and cobalt as cathode are contributing towards environmental degradation such as: ecological toxicity, resource depletion, global warming and several health issues. The production and processing of these elements might cause pulmonary, respiratory and neurological issues. The mining and extraction of lithium from hard rock require the toxic process which can cause the water pollution, air contamination, hazardous impacts on food production and damaging soil which consequently damage the ecosystem. European Commission on Science for Environmental Policy has also reported the social and environmental impacts of lithium-mining, and further suggested the monitoring of process and locations for possible protection. Therefore, facilities should be provided by the government for appropriate and fully manageable recycling of li-ion batteries to ensure the clean and safe environment [127].

A report [128] "Mission 2016" evaluated the overall mining process and its environmental impacts. Mining contributes 9600 to 12000 cubic meters of toxic gas release in China for each ton of rare earth element extraction. The process additionally produces 75 cubic meters of acidic water and a ton of radioactive waste. This industrial process requires a lot of energy and if generated through fossil fuels would increase the carbon emissions. Such industry demands for effective regulations and emission credits to maintain the environmental standards. In this report "Mission 2016" plan is proposed to regulate the mining process for greener mining with recycling prospects [128].

A study [129] suggested the environmental gap between EVs based on lithium ion batteries and IEC vehicles is not much prominent; the gap is narrowed due to mining and recycling process of Lithium ion batteries which are contributing towards in health, ecosystem and global warming issues. EVs Charging depending on coal power generation estimated 17-20% worse than its diesel and gasoline counterparts. The energy required for EV and battery production is almost double and adding more carbon foot prints in comparison to gasoline type vehicles.

The study in [130] pointed out the harmful social impacts caused by lithium mining process. The contamination and diversion of source water for local communities in arid region is a major concern for environmental agencies, a lithium mine in Bolivia affects the use of 50,000 tons of fresh water per day. High quality lithium is concentrated in few regions around the world and its mining extraction and transportation are imposing negative economic, environmental and social impacts.

The cheapest method for lithium extraction uses the toxic PVC to evaporate salt brines in solar ponds. The mining and extraction of pure lithium requires extensive operation and water treatment. The alkaline characteristics of lithium results in destruction of approximately 2/3 of fresh water in mining area of Chile which further affects agriculture, live stocks and life of local communities. The processing produces toxic chemicals and emits hazardous dust causing cancer, neurological and respiratory problems [131].

The environmental impacts evaluated in all abovementioned studies showed that the negative environmental impacts of EVs can be realized, when charging phenomenon is performed through pollutant generating power units. However, with an increase in renewable energy integration to power networks and optimized charging strategies, a significant reduction in "Well-to Wheels" emissions can be expected [132].

C. POWER GRID IMPACT ASSESSMENT OF EVS:

The rise in massive EVs penetration introduces a significant additional charging demand which can generate certain undesirable impacts on the power system. This situation specifies that the power grid is facing the increase in load profile during peak hours, over loading of power system components, transmission losses, voltage deviations, phase unbalance, harmonics and system stability issues, which degrade the power quality and reliability of the power system. The impact assessment of EVs is based on various substantial conditions such as:

- Various Levels of EVs Penetration
- Strategies of Charging
- Different Characteristics of EVs Battery
- Location of Charging
- Charging Patterns
- Charging Time
- Battery State of Charge
- Profiles for Fleet Charging
- Driving Patterns for EVs

- Driving Distances
- Tariffs
- Demand Response Techniques [133-137].

Therefore, several studies are performed to evaluate power grid impact analysis with large scale EVs integration. The impacts assessment of EVs on distribution grids can be classified as mentioned in figure 7.

1) BENEFICIAL IMPACT V2G TECHNOLOGY

EVs with bidirectional chargers provide a distinct benefit as means of a technology acknowledged as vehicle-to-grid (V2G) technology. When batteries of EVs are not in use, but still connected to a network, they can provide energy to a power grid at its highest demand of load and therefore enhance the efficiency of grid, this refers to a V2G technology [7], [9], [136]. The expected increase in penetrations of EVs makes it possible to implement V2G technology. Bidirectional charging leads to the possibility of power flow in both directions in between power network and EVs. EVs are capable of serving as load as well as providing energy to the grid. As far as utilities are concerned, EVs can be viewed as load and source of generation by acting like back-up generators at level of distribution. EVs have the feature of offering supply and storage services to power networks. For charging the EV battery and to support the power network, the bidirectional power flow employs the concept of energy exchange between the power networks and the batteries of EVs. The bidirectional power flow with the help of V2G technology enhances the flexibility for power network to control the stored energy mechanism in batteries of EVs and to maintain sustainability, reliability and efficiency of a power network [138],[139].

The substantial benefits provided by bidirectional V2G technology are: support to active power and reactive power, sustenance for power factor regulation and helps to improve the integration of variable renewable energy resources. The load balancing by valley filling and peak load shaving are one of the main features that can be achieved by bidirectional V2G. [54],[140-142]. The wind and solar photovoltaic are such kind of renewable energy resources (RES), that the power generated from them is of unpredictable and inconsistent nature. This is one kind of major drawback of RES as weather conditions have a major impact on them. Interaction of EVs with renewable energy resources is an emergent solution to resolve the intermittent nature of RES by utilizing the EVs as pool of storage capacity.

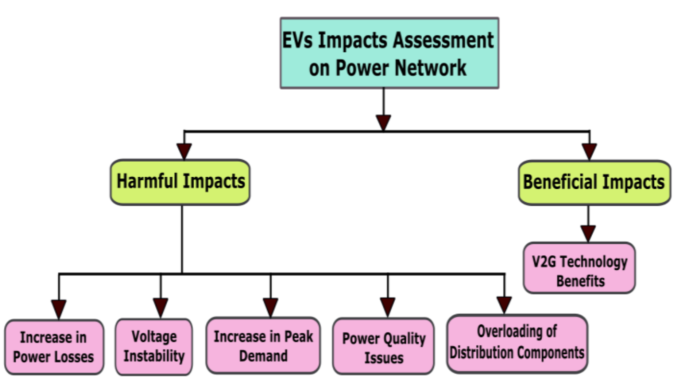

Figure 7: Classification of EVs Impacts on Distribution Grid

2) ISSUES OF VOLTAGE INSTABILITY AND PHASE UNBALANCE

Voltage instability is one main cause of the occurrence of major blackouts in a power network. The cause of this condition is that the power network is usually operated up to the stability limits of the system and suffered from extreme load demands. The instability problem can also occur due to different characteristics of various loads [143]. However, the stable power networks have the capability to perform imperatively and to certify the reliable transfer of power to users. The characteristics of conventional household loads/industrial loads are different from the load characteristics of EVs [144,145]. The battery load of EV takes more power to recharge fully in a shorter time and behave nonlinearly. The stability of grid voltage is significantly affected by the load characteristics. The issues of voltage deviations and voltage drops will occur in the distribution networks as well as on the interconnection point for EV due to higher EV charging demand from the distribution grid.

To analyze the impacts of EVs charging on the gird voltage deviations under tolerance level of 7% (Chinese standard for 10KVA distribution Grid) a Monte Carlo simulation approach is proposed [146] that is intended for two scenarios, namely: uncoordinated charging method and V2G technology. The results suggested that in V2G charging mode the voltage levels are in a controlled manner up to 90% of EVs penetration, according to Chinese standards. However, for uncoordinated charging method penetration levels of 60% or above violates the tolerance level and severely deviates the system voltages. The V2G charging method is capable to perform the load balancing and ensure the small voltage gap between peak and off-peak load demands. Another study [147], implemented smart charging strategy to maintain network voltage in acceptable tolerance range, which otherwise violates at 50% EVs adoption rate.

The Level 1 slow charging performed at residential areas may suffer from the phase unbalance problem due to uneven EV charging distribution among all three phases. A severe phase unbalance condition is observed in a study [148], where all EVs are connected on single phase ‘a’. The results recommended that significant phase unbalance can occur in the system and require additional focus for EVs integration in future. A slight impact on voltage and current unbalance is observed in [149] due to EVs integration into the power network. However, issue of phase unbalance is controlled by various testing conditions. A genetic algorithm is proposed to optimize the charging of EVs across different phases and to control voltage unbalance issue [150].

In [151], an EV load model was developed in Simulink environment based on constant power and negative exponential load components. The model simulation is performed in IEEE-

43 bus distribution network, and voltage stability is examined based on load margin for several factors such as power factor, location and number of charging stations. The results obtained from the study showed that EVs fast charging is highly considered for reducing the voltage stability of a distribution network. In another work [152], IEEE-39 bus feeder network is used to achieve simulation, and modeling of power system is performed in Open-DSS software. For the given purpose, comprehensive travel patterns are utilized. The higher power charging levels with large-scale integration of EVs is majorly answerable for voltage instability scenarios in the power network. However, optimized charging technique is extremely useful to improve the reliability of the distribution network.

Moreover, in [153], the authors showed that EVs can be adopted by power network as a constant impedance load before voltage instability is realized. The issue of voltage instability due to various penetration levels of EVs is improved in [154] by employing a wide area control technique which overcomes the fluctuations during charging as well as discharging modes of EV battery. Another method to reduce the voltage instability issue is proposed in [134] based on voltage control technique by tap-changing transformer. The authors suggested that appropriate planning techniques for charging infrastructure of EVs are required to alleviate the impact of voltage instability on power grid. The planning techniques for charging stations basically depend on parameters such as: optimal sizing of charging stations, charging time scenarios and appropriate site location.

In [155], the concept of EV parks is introduced and a technique improving the power quality is explained when large scale EV loads are integrated into the system. A Spanish grid code P.O.12.2 is used for power injection coordination in a medium voltage grid, fed from Photo-Voltaic inverters after a probabilistic EV load forecasting. PSCAD/EMTDC is utilized to study control loop dynamics and the obtained results verified that the proposed coordinated charging solution enhance the power factor, increase voltage stability and provide support to frequency profiles.

Several numbers of technical studies [146-159] were conducted to investigate the impact assessment of EVs charging scenarios on voltage stability, voltage drops, voltage deviations and phase unbalance. The results obtained from these research studies showed that different penetration levels of EVs may or may not have a significant impact on the abovementioned voltage related factors. Several important factors are considered which influence the impact results such as: interconnection point of EV, different penetration levels, charging characteristics of EVs and many others. The characteristics of EVs load are dissimilar from the conventional loads as power demands of EVs cannot be estimated earlier. As a result, the probability of violation in parameters of distribution components may increase if large number of EVs are integrated into a power network. Hence, load management across all three phases, voltage regulation equipment, voltage support techniques and appropriate load modeling of EVs can be employed to sustain the voltage profile of a power grid without violation in future.

3) IMPACT ANALYSIS OF PEAK DEMAND AND LOAD PROFILE

Numerous research studies have been conducted to analyze the impact of EVs charging strategies on load profile and peak demand of a distribution grid. Various distribution grids in different countries are chosen to perform these impact evaluations. In [160], the investigation was carried out regarding considerable peak demand due to massive deployment of EVs. The authors found that 100% penetration level of EVs with uncoordinated charging method impose peak demands that exceed the available production capacity of electricity on average load days. As a result, if no additional generating resources are integrated into the distribution network then up to 93% EVs load must be accommodated during off-peak hours. In a similar study [161], the impact of uncoordinated charging scenario with 30% EVs penetration level increased the peak demand up to 53%. In [162], EVs penetration level up to 10% significantly increased the peak demand due to uncontrolled charging in residential areas. In study [163], the substantial increase in peak demand is observed even under normal EV charging scenario. Therefore, optimal charging condition is needed.

On the other hand, in [164,165], the authors identified that even without the additional generating capacity; only the time-of-use tariff plans and optimized charging conditions can considerably alleviate the peak demand. In studies [166,167], the authors examined that the distribution grid at Ontario, Canada can integrate around 500,000 PHEVs for charging purpose without any significant impact on the grid. In a similar study [168], the authors demonstrated that up to 73% EVs penetration level can be tolerated by the prevailing grid network capacity of the US.

A technical study [169] is performed on a German grid for the year 2030 to analyze the EVs charging impact on the load profile. The authors found that with uncontrolled charging of 1 million EVs the German grid shows a minor impact of 1.5% increase in the peak load. However, it is doubled if 42 million ICE vehicles (Total approximate number in Germany) are replaced by EVs. The study also revealed that 16% reduction in peak load can be realized by utilizing 1 million EVs as grid stabilization storage devices. A study [170] on Estonian grid is performed with EVs penetration level up to 30% of passenger vehicles available. The results found an increase of 5% in peak load for uncoordinated charging and increase of 4% for coordinated charging. Moreover, the controlled charging strategy performed during night time can level the load profile. In [171], an hourly based analysis on Korean grid is realized, considering some parameters which include EVs charging location, rates of EV charging, EV specifications and usage time for the year 2020. The authors showed that the additional charging scenarios for EVs can affect the reliability of the distribution grid. However, time-of-use (TOU) tariff plans are suggested to resolve the issue of peak load profile.

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In study [172], the authors presented a smart charging strategy in order to prevent residential and EV peak load overlapping. Number of charging possibilities with different charging capacities and pricing options are proposed including Level 2 charging, AC charging, DC fast charging and battery swapping option. Queuing model is used to estimate the delay at different charging stations, and partial charging concept is used to prevent EV and residential peak load overlapping. The optimal problem sets to find minimum charging time, cost and travel time which provides the optimal solution for an efficient charging station. An extended meta-heuristic-based colony optimization is performed, and the proposed results demonstrated that reduction in charging cost up to 15% and in waiting time up to 25% are observed.

Finally, the EVs are an added load to distribution network, so massive integration of EVs will affect the load profile of a system. The random charging behavior of EVs owners increases the probability to select the peak load hours. Therefore, massive EVs penetration with different charging conditions will significantly enhance the peak load of the distribution grid [173-176]. Fortunately, optimized charging solution, TOU plans and RES integration [177] can be employed to solve the peak demand and load profile issues of the power network.

4) HARMONICS IMPACT ANALYSIS

The involvement of power electronics devices in charging operation of EVs may arise the power quality problems in distribution network due to the occurrence of switching phenomenon. The harmonic issue is needed to consider significantly as harmonic distortion plays a major role in derating of distribution components. The supply quality of power network can be affected due to massive integration of EVs. In charging process of EVs, the arbitrary number of EVs batteries with random demand of energy may lead to a demand side management issue [54]. The current and voltage spectra are used to represent harmonics. The unwanted values of these spectrums are expected in a power network due to non-linear loads, for instance, EVs. The current and voltage total harmonic distortion (THD) values can be presented in terms of percentage as mentioned in Eqs. (1) and (2) [72,178].

$$THD_i = \frac{\sqrt{\sum_{h=2}^{H} I_h^2}}{I_1} \times 100\,\% \tag{1}$$

$$THD_v = \frac{\sqrt{\sum_{h=2}^{H} V_h^2}}{V_1} \times 100\,\% \tag{2}$$

Where,

h = Harmonic order number

H = Highest number of harmonics

I_h, V_h = Current and voltage RMS Values at hth harmonic component.

I_1, V_1 = Fundamental frequency components values of current and voltage.

In [179], no substantial harmonic issue is observed due to EVs charging scenarios. The voltage THD value is increased to some extent i.e. less than 1%. A comprehensive harmonic study [180] is carried out using Monte Carlo simulation method considering dynamic EV characteristics including the charging time and the charging location. The results showed nearly insignificant harmonic impact on the distribution network. The results obtained from some case studies also suggested minor harmonic impact on power grid.

On the other hand, in study [181], the authors examined an increase in THDv level of 11.4% due to EVs rapid and random charging which violates the limit of 8% according to EN 50160 standard. The control of PV inverter as an active filter is a suggested solution to reduce the issue of harmonics. The results obtained from similar harmonic studies showed an increase in THDv level which is beyond the accepted limit [182,183]. In [183], THDv up to 45% is observed by randomly charging of 18 EVs during the peak hours. The improvement in system performance can be observed by implementing uniform charging schemes. In contrast, high THDi from 12%-24% is observed in [184] due to rapid charging scenarios. The higher range of THDi may create severe impact on the performance of the residential power grid. In [185], the authors utilized fluke power quality analyzer to observe power quality issues and performed harmonic measurement to achieve harmonic spectrum of current and voltage in real time situation. The results showed that EVs charging may generate harmonics in relation to THDi and THDv values. The study also found that THD is not a linear multiple factor with massive integration of EVs to power grid.

Generally, a distribution gird endures several types of non-linear loads to supply the essential power to customers. As a result, various patterns of harmonics can be observed in a power network. However, cancellation of harmonics may be realized in a grid due to different load patterns [186]. The probability of harmonic cancellation may be increased with a high number of EVs owners. In [186], the authors performed a comparative based analysis on four conventional EVs chargers including single and three-phase rectifiers, square wave and pulse width modulation (PWM). The obtained results showed that the unpredicted induced harmonics due to various non-linear loads can be alleviated by utilizing PWM chargers. The Supply THD or selected harmonics can be reduced automatically from PWM EVs chargers [186].

In [187], the authors proposed a solution to overcome the issues of power quality. The idea is based on designing a power conditioning unit (PCU) that only permits the controlled charging scenario of EVs. The PCU is compatible with the smart grid to perform the appropriate power management. The experiments performed on PCU are based on battery charging and discharging mode, inductive, and capacitive handling situations. The results from the revealed that the suggested idea of PCU can reduce the power quality problems of power network by solving voltage degradation issue, reducing THD value, and achieving reactive power compensation for EVs batteries. The higher THDi value can be reduced by employing the filtering devices in the supply system.

Finally, various research studies [179-189] performed for harmonics impact assessment obtained different outcomes. The results obtained from some studies showed a minor harmonic impact on distribution network. However, some technical studies examined negative impacts due to EVs charging scenarios. The variance in results obtained from different harmonic impacts technical studies is purely based on methods of system studies and EVs charger modeling characteristics. Various solutions are obtained from several implemented research methods to deal with harmonics issues such as filtering devices can be included in the power charging circuits.

5) IMPACT ANALYSIS ON DISTRIBUTION COMPONENTS AND SYSTEM LOSSES

A large amount of power is required to be transmitted from power plants to cater the huge load demand required for a large-scale integration of EVs. The distribution system components may face overloading situations as in conventional grids the distribution components may not be modelled to suffer from added EV loads. The bulk charging scenario of EVs may cause the overloading of network components including the power conductors and power transformers. The distribution transformers and conductors will be at great risk and in stress situation due to large-scale deployment of EVs. The non-linear characteristics of EV chargers may cause harmonic distortions which further create powerful stress on fuses, cables and power transformers [145,190]. The authors in [190] examined the conductor loading for peak charging hours of EVs. The obtained results showed that for slow and rapid charging conditions the cable can safely handle 25% and 15% penetration levels of EVs correspondingly. The study concluded that massive integration of EVs cannot be catered by the distribution networks easily.

Various studies have been considered to analyze the impacts on the distribution components and on the power losses of the network [191-193]. In a study [191] the authors examined the transformer aging based on the charging power levels 1 and 2 (AC). The distribution transformer suffered from more aging impact in case of uncoordinated AC power level 2 charging. For level 2 charging condition, aging factor of up to 8.15 is observed in comparison with 3.24 in case of level 1 charging. In a similar study [191], huge penetration of EVs can exert harmful impacts on lifespan of transformer. In contrast, authors in [193] showed that transformers can safely mange the load demand of EVs for power level 1 charging, and uncoordinated charging with power level 1 has a minute impact on transformer life; however, uncoordinated charging condition with massive integration of EVs severely affect the transformer life and may cause failure of transformer due to worst operating temperature. The lifespan of transformer can be improved by appropriate load management and off-peak charging scenarios [191-193]. The study in [194] showed a massive increase in loading of 400V secondary side cable of 20KVA distribution network during EV fast charging. In a similar study [195], the authors considered the Finnish distribution network to analyze the EVs impact on power cables. The real-time load profile showed an imperceptible effect on medium and low voltage cables due to different charging scenarios of EVs. In [190], the random distribution of EVs load is performed throughout the proposed distribution network model. The standard IEEE C57 is used to find the aging factor/loss in transformer life. The outcome of the study showed that due to cool weather in Vermont the fully loaded 10KVA distribution transformer has negligible impact in relation to annual aging of the transformer. However, high ambient temperature may cause an increase the aging factor of the distribution transformer. In [196], the authors revealed that for level 1 and level 2 charging conditions the overloading in distribution transformers is observed up to 20% and 10% penetration levels respectively. The authors performed several case studies and concluded that fully loaded distribution transformers may create a bottleneck situation due to massive integration of EVs in case for random charging scenarios [197].

A multi-station coordinated charging strategy is proposed in [198] based on estimated PEV charging models with a significant attention on charging cost minimization. The proposed model considers the parameters such as charging demand, voltage, power flow, branch thermal, charging power and balance power constraints. Monte Carlo method is used to analyze the PEV parking behavior and concluded results showed a comparison between coordinated and uncoordinated charging schemes. It proposed large-scale PEV penetration into a distribution grid under the coordinated charging strategy.

A typical study [199] on a low-voltage distribution network in Greece examined the high photovoltaic and EV network penetrations under European Union policies. A distribution network might experience both over and under voltage scenarios under EV and photovoltaic penetrations at different times of the day. The study performed stress analysis on a distribution network and proposed necessary storage system to keep voltage under prescribed limits

The Impacts on power distribution system are explained in study [158], and a charging management system is proposed to control PEV charging activities. A three-tier algorithm controlling the PEV charging by rolling the station and prioritizing low battery PEVs is used for evaluation in a 14.4kV distribution grid with charging data attained from Los-Angeles Power and Water Department. The results showed a considerable rise in voltage drop under heavy loading after two control cycles. An increase in voltage supply capability and 14.5% improvement in state of charge are also realized as compared with two-tier control mechanism.

Finally, after the assessment of several research studies it is evaluated that random charging scenarios with level 2 charging condition and massive penetration can severely impact the distribution components, especially the power cables and power transformers. The significant factors that majorly influence the outcome of the power grid study are:

- Appropriate selection of power transformers
- Various system configurations
- Ratings of various components

- Component loading scenarios
- Various level of penetration
- Strategies of charging and Proper System planning
- Proper load scheduling and Smart metering
- TOU plans

The EVs are additional loads to a power network, therefore all the above-mentioned factors are recommended and need to be considered for future EV adoption.

a) POWER LOSSES ASSESSMENT

The large-scale integration of EVs can disturb the reliability of the power grid and increase the probability of grid components losses. The problem of power losses arises major concerns for utilities due to extra losses of power network by additional loads of EV. The feeder power losses in a distribution network can be calculated as [200]:

$$P_L = \sum_{i=1}^{N_B} I^2 R_i \tag{3}$$

Where,

I = Current

Ri = Resistance of feeder i

NB = Number of distribution network feeders

The additional power losses arise due to different charging conditions of EVs can be implied as mentioned in eq.4 [201].

$$AP_L = TPL_{EV} - TPL_{Origin} \tag{4}$$

Where,

TPL_{EV} = Total losses during EVs charging/Connected to grid

TPL_{Origin} = Total losses with no EV connected to grid

Several technical studies have been performed to analyze the EVs impact on system losses. The authors in [202] investigated the charging impact of EVs for Danish distribution network. The outcome of the study showed that up to 50% level of penetration in uncontrolled charging scenario increased the system losses by 40% and coordinated charging reduced the grid losses to 10% in comparison to a base case with no EV integration. A probabilistic approach is employed in [165] based on charging time, charging rates and total duration of charging to measure the network losses in relation to massive penetration of EVs. The simulated results showed that massive integration of EVs increased the power losses of distribution network. In [203], simulation is performed on a huge distribution model to examine the power losses. The arrival time and charging patterns are not considered for the study in case of 85%EVs charging during off-peak time and remaining charging of EVs at peak time duration. The obtained result for one scenario showed an increase in power loss by 40% during off-peak charging even when 60% EVs are integrated into the power network. The uncoordinated charging strategy of EVs with large penetration of EVs can result in higher system losses. Therefore, in [204], the authors suggested an optimized objective function in relation to coordinated charging to mitigate the power losses. The study employed the stochastic programing to achieve an optimal solution with reduced power losses of the network due to unavailability of appropriate load forecasting. A significant increase in distribution transformer losses is assessed in a test radial network of 1200 node with load profile of Australian residential houses [205]. The EVs penetration levels up to 42% are considered at 415V bus, which increase the transformer losses by 300% for higher EVs penetration.

Finally, the outcome of various technical studies suggested that amount of power flow is increased due to EV charging scenario. As a result, the system losses are increased. The coordinated charging strategy can be employed to mitigate the EV charging impact on network losses. Moreover, EV loads should be accommodated by nearest distributed generation to reduce power losses of the network [206].

In conclusion to all above discussions, the EVs have substantial beneficial impacts as well as harmful impacts. The beneficial and harmful impacts of EVs with corresponding benefits and remedial measures are summarized in Table III.

VI. CHALLENGING ISSUES AND PROSPECTS

The development and deployment of EVs can be considered as a resolution and promising approach towards the electrification of transportation system. In the transport sector, EVs are the forthcoming option for the upcoming generation. The major scenarios in the transport system which arise the need to utilize the alternative resources of energy are: sudden change in climate, fossil fuel depletion and rising prices of crude oil. Several benefits can be achieved from EVs in relation to environmental, economic and power gird impacts. From the grid and environmental perspective, the technology of EVs is much energy proficient and cleaner approach in comparison with conventional IEC vehicles due to zero CO_2 emissions. Many new opportunities can be realized by EVs deployment such as advancement in V2G technology and tracking of RES. The integration of V2G technology with RES can create many environmental, economic benefits, and many regulatory services provided to power grid. Nevertheless, many challenging issues and limitations still need to be addressed and overcome before the efficacious employment of EVs in the market. Some of the key design and technological challenging issues with future trends for widespread employment of EVs are summarized below:

- ❖ The starting price of EV is still much higher in comparison with conventional IEC vehicles due to higher cost of EV batteries.
- ❖ Despite the remarkable advancements in battery technology, the current charging technologies are not fully developed. The limitations of the current Li-ion batteries are lower energy density and reduced life cycle. Maintenance is required after one to two years due to limited life cycle. Moreover, the weight and size of batteries are approximately one-third of the vehicle. The superior performance can be achieved from few battery technologies, but they are in an experimental stage and not fully matured.
- ❖ The development is needed for efficient battery management systems to achieve optimal performance of batteries. The

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TABLE III
Beneficial and Harmful Impacts with Corresponding Benefits and Remedial Measures

Beneficial and Harmful Impacts	Benefits and Remedies
Benefits	
V2G Technology	▪ Alternative source of energy at peak hours. ▪ Increase in reliability of the system. ▪ The overall cost of the system is decreased [54,207]. ▪ Line losses and voltage drops are reduced for distribution network. ▪ Power quality issues are minimized. ▪ Reduction in frequency fluctuations. ▪ Voltage stability issues are reduced. ▪ Ancillary Services
Environmental	✓ Green solution for road transport system. ✓ The emissions of CO_2 and other pollutants are reduced.
Economic	➢ The fuel and operating cost are reduced. ➢ Users can get benefits by supporting V2G concept.
Remedial Measures	
Power Quality Issues	• Fulfill the requirements and recommendations given in standards based on harmonic control such as: EN 50160:2000, IEEE 519-1992, IEC 61000-3-12/2-4. • Employing PCU compatible with smart grid for coordinated charging. • Utilize voltage source inverters and current control of inverters to improve harmonic issue. • Employ harmonic filter at supply side. • Utilize smart appliances having banks of passive filters [327]. • Smart grid environment with suitable load management approach.
Transformer overloading	➢ Employing smart load management techniques. ➢ K-factor derating method is employed.
Increase in Power Losses	✓ Uniformly distributed charging ✓ Coordinated control charging.
Increase in Peak Demand	▪ Smart and controlled charging. ▪ Valley Filling approach. ▪ Smart multiagent metering system.
Voltage Instability	➢ Use of Tap changing transformer. ➢ Wide area control method to reduce fluctuations.

designing procedures involved in sizing the battery subsystems need to be improved. High performance, maximum range and greater life cycle of batteries are achieved through appropriate choice of battery subsystem.

❖ The current charging technology of EVs has certain restrictions in relation to V2G technology. The battery chargers are not fully matured for V2G deployment in smart grid environment. In the present situation, unidirectional chargers are mostly adopted in the market. However, advance bidirectional chargers are needed for standardized V2G implementation. Therefore, additional focus is required for advance research techniques in planning and development of bidirectional chargers.

❖ The V2G technology is an alternative solution to cater many significant issues of a power network. It can accelerate the integration of RES. However, V2G concept requires the significant involvement of EV owners. At the same time, new management policies and some reward schemes should be introduced to motivate the EV owners to majorly participate in V2G implementation. Otherwise, implementation of V2G technology becomes difficult. As a result, comprehensive technical studies need to be implemented to realize the best possible solution which is based on energy management techniques and reward-based schemes.

❖ The existing infrastructure of power network may not be effectively designed and up to date to sufficiently manage massive and necessary demands of EVs. For the implementation of V2G technology, high investment is needed to effectually update the conventional power infrastructure. Additionally, a fully updated charging setup with satisfactory installed EVs is required for successful implementation of V2G structure. Moreover, the excessive cycling process of batteries may increase the energy and conversion losses. Proper planning techniques with advanced research methods are necessary for deployment of a such complex infrastructure.

In considering all afore-mentioned substantial aspects, the prosperous implementation of whole EV infrastructure is dependent on certain factors in future, which are suggested as follows:

➢ In the present situation, the owner's anxieties about cost, driving range, durability and time duration of charging are still present even with number of economic, environmental and smart grid benefits. The advancement in battery storage technologies can be one possible solution to lessen some of these concerns. Currently, more benefits can be achieved from advanced lithium-sulfur batteries in comparison with li-ion batteries. The attractive benefits are extended range of temperature, higher energy density, improved safety performance, and above of all the reduced cost due to easy accessibility of sulfur material. However, these lithium-sulfur batteries are not commercialized substantially. Moreover, issue of self-discharging is observed in this battery and capacity is reduced due to rapid charging and discharging cycles. Comprehensive technical studies need to be performed for advance modelling of batteries to achieve safe and reliable charging and discharging operation, optimum utilization and reduction in size and weight.

- Development of charging infrastructure with required EVSE should be significantly considered for safe and controlled energy transfer to EVS.
- Customer acceptance can be enhanced by employing desired safety standards, increased reliability, durability and the efficiency of battery charger with reduced charger cost.
- The modernization of power system accelerates the utilization of EVs in terms of V2G technology. In smart gird environment, EVs become a possible solution to balance the power fluctuations due to intermittent nature of RES.
- The infrastructure of EV charging based on smart charging strategies should manage the high power fast charging to facilitate the owners and to minimize the range anxiety of EVs customers.
- The charging infrastructure in residential and commercial areas with its related equipment and software should be user-friendly for wider acceptance.

VII. CONCLUSION

This paper inspects the present status, latest deployment and challenging issues in the implementation of EVs infrastructural and charging systems in conjunction with several international standards and charging codes. It further analyzes EVs impacts and prospects in society. The paper highlights international standards regarding charging methods, grid integration, power quality issues, safety limitations, communication networks and equipment maintenance which are required for large-scale deployment of EVs. Furthermore, a complete assessment of charging systems including: inductive charging, conductive charging and battery swapping networks for EVs with various kinds of fast and slow battery charging techniques is explained. Moreover, the beneficial and harmful impacts of EVs are categorized and thoroughly reviewed with remedial measures for harmful impacts and prolific benefits for beneficial impacts. Bidirectional charging offers the fundamental feature of vehicle-to-grid technology. The optimal charging methodologies should be adopted to control the issues of EVs impacts.

The efficacious realization of V2G technology and electrification of transport sector are unquestionably continuing motivations. Nevertheless, the V2G technology is a captivating research outlook, which can bring numerous potential economic and environmental benefits and provide various services to power network such as tracking of RES. The current challenging issues of EVs for massive deployment of EVs, as well as upcoming research trends are also presented.

This paper brings forth a balanced and comprehensive analysis of more than one sub areas being currently explored in EV research. The paper contributes towards an overall picture of electric vehicle grid integration with special emphasis on EV charging technology, international standards, charging systems, slow and fast charging techniques, impact analysis, technical challenges and prospects. The successful employment, expansion and appropriate operation of EVs in upcoming future days are directly linked with the establishment of new international standards and charging codes, reward-based policies, increased awareness of customers, suitable infrastructure, smart and efficient chargers, advancement in battery technology and software at public and private locations that should be more user-friendly. Numerous benefits achieved from EVs will undoubtedly get a considerable attention from utility operators and EVs owners in near future. It is intended that the researchers involved in such research area can find this paper valued and an informative one-stop source.

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