Original Research

A Comprehensive Review on Charging technologies and International Standards for Electric Vehicles

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Abstract
The enormous growth in the transportation sector around the globe has led to the emission of greenhouse gases in the environment contributing towards climatic change and global warming. The multifaceted solution to climatic change is achieved by zero emission operation of automobile sector by transforming towards fully electric. With the advancements in electric drives, the operational emissions of Electric Vehicle (EV) are completely eliminated and the emissions related to power generation can be eliminated by focusing on renewable energy sources. However, in many countries the demand for electric vehicles contributes only to a lesser percentage of vehicles. The key barrier in implementing massive adoption of green energy vehicles is the energizing time. Moreover, several difficulties related to formation of energizing plan include concern by the driver to reach the destination, lack of groundwork for charging and high cost of EV. This paper provides thorough examination on recharging methods, worldwide standards, and the challenges associated with the future research. The summary of different recharging methods with regard to conductive or wired charging, battery switching and cordless charging are discussed. A comparative analysis has been carried out on different charging levels and commercial onboard chargers in terms of distance, voltage and capacity of battery, time and power of charging. Furthermore, future roadmap and challenges in implementing EV are encapsulated as the future research investigations.

Keywords - Electric vehicle, Recharging methods, Worldwide standards, Fast charging techniques, Global warming.

INTRODUCTION

Environmental sustainability is the substantial concerns of the nation around the globe. The environment is degraded by many factors like industrial waste, rising energy use, economic growth, increase in population, transportation, electricity generation process, agricultural industries and commercial and residential buildings [1]. About one fourth of world's greenhouse gas emission comes from the transportation sector [2], [3]. The promising solution for diminishing greenhouse gases in the environment by the transportation sector is to flourish electric vehicles by reducing the consumption of natural gas [4], [5]. Electrification is the major factor that contributes to both social development and economic growth. Therefore, the transformation of internal combustion vehicles to green energy vehicles by transportation division focuses on energy transition towards zero carbon emission. The main advantage of using electric vehicles is that it offers zero emission, high reliability, and low maintenance cost of electric motors than internal combustion engines. Instead of non-renewable energy sources (fossil fuels), the EVs provide opportunity for employing alternative energy namely green energy sources and the energy repository system to secure electric mobility. The recharge time of green energy vehicles is the main challenge related to the internal combustion vehicles. With the enlarged acquisition of EV over a short span poses grid reliability issues/ capacity of generation and the increase in load demand caused by extended EV usage may affect the distribution grid reliability [6-8]. Thus, the stability and reliability of the grid is affected by faster energization of EVs through DC supply. The fear of EV driver can be reduced by matching the driving range with internal combustion vehicles by the developments of recharging infrastructure. Based on the forecasting of EV sales, it tends to increase from 2020 to 2025 of about 10.9 million, which is possible with the developments in charging technologies [9].

EV adoption is made possible with the advanced charging methodologies. Another keystone in EV adoption is the battery technology, in the overall cast and weight of EV the one-third portion is constituted by battery [10]. Owing to the developments in charging technologies still there is a problem in widespread acceptance of EVs caused by the challenges of complex charging framework, energizing time, driving range, reliability issues, battery cost and battery lifetime. The reliable and cost-effective operation is possible by adopting proper power conversion technology and implementing newest control methods with high power providing improved efficiency [11], [12]. The EV chargers and charging system comprises of distinct power converters to charge the battery safely with high competence. The power delivered by the charging system is either unidirectional or bidirectional. The converter topology determines the fulfilment and effectiveness of the energizing system. The energizing time can be reduced by using high power converters. With the increased fleet of EVs the demand for electricity increases injecting power quality problems into the grid. The increased demand is satisfied by proper forecasting of load and the generation of electricity can be planned with the help of green energy sources which improves the safety and reliability of grid. To strengthen the fall back on EV charging technologies, distinct power converters and grid integration techniques are flourished.

Therefore, in-depth examination of EV recharging technologies, worldwide standards and future challenges is essential to provide remedial solution to the challenges in implementation of electrical mobility. Most of the charging stations are AC powered with converters to deliver power to the EV loads compared to DC fast charging and ultra-fast charging technologies. In recent years, DC power charging stations are most popular with the advancements in power converter design, fast charging, high efficiency and flexibility in power transmission from grid to EV. Hence a comprehensive analysis on the technical development, challenges and the standards are made to provide a possible solution for fast charging of EVs. This paper focuses on the following contributions. Firstly, it presents the overview of distinct EV charging methods and the preference of current state charging technologies. Secondly, various standards of grid communication, component safety, charging methods, battery testing methods, battery swapping are discussed. Finally, future roadmap, announcements and challenges of EV charging are introduced and the final observations are figured out in the last part.

BATTERY CHARGING METHODS

Environmental aspects have brought a significant concern over the past few years due to its impact on communities worldwide, which increased the percentage of electric vehicle usage than the commercial internal combustion engine driven vehicles. The core technology in implementing EV is the battery charger, where battery acts as a main power source. The power to the battery is supplied by two different types of battery charger. Firstly, the offboard charger with a power capacity of more than 350 kW, charges battery completely with a timespan of approximately 5 min. Secondly. The on-board battery charger uses a residential power source to charge a battery of capacity 1.92 to 19.2 kW. Presently on-board battery chargers of lower power rating are used in EVs, with an idea of charging at owners' residence during night-time.

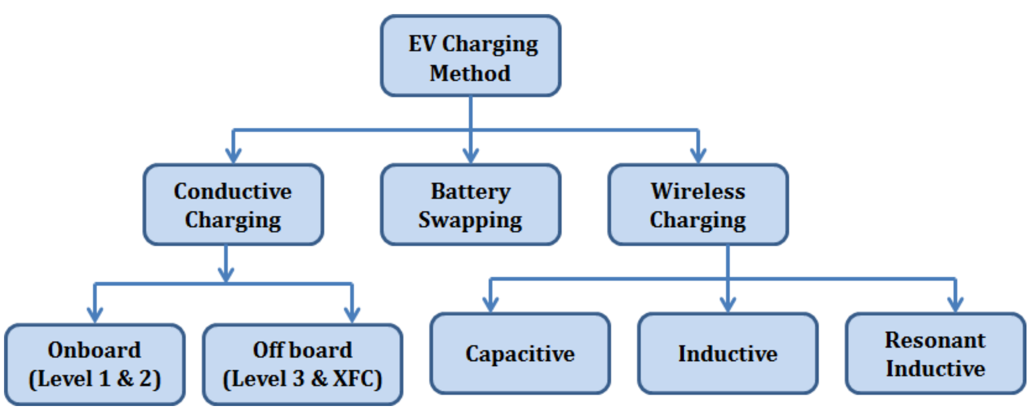


FIGURE 1
DISTINCTIVE EV CHARGING METHODS

EV Batteries are charged using distinctive charging methods and objective application employed. The distinctive charging methods specifies the magnitudes and the shapes of the Currents/Voltages when energizing, whereas the objective application refers to transfer of energy to vehicle in a physical mode.

I. Conductive Charging

Conductive charging necessitates the active connection between the vehicle contact and the charging inlet with distinctive energizing levels in accordance with the rate of power transfer which includes level 1, level 2, level 3 and extremely rapid power transfer as displayed in Table I.

II. On Board Battery Charging

The on-board battery charger (OBC) uses residential power source for charging a battery (from 1.92 to 19.2 kW). Since the charger is implemented in vehicles it has to be small and light. In addition, for expanded battery voltage i.e., from about 120–240 V the variable voltage control of OBC is required. In order to achieve the requirements as specified, previous research has been implemented with the successive examination [13]:

- The switching control employed in OBC for achieving small volume and light weight is carried out at higher frequency;
- To fulfill the variation in input and output voltage the transformer with both step-up and step-down operations are perceived;

Level 1 and Level 2 onboard charger uses AC power supply and same standards for transferring power to the EV. The domestic or Level 1 power transfer employs 120 V supply providing low power of 1.92 kW and has deliberate power transfer compared with all other levels [14], [15]. Hence for overnight or elongated charging, Level 1 charging is preferred. It requires longer time duration of about 11-36 hours for charging an EV of 1.9 kW power level with a rated capacity of 16-50 kWh [16]. For both private and public charging facility the primary charging method adopted is Level 2 charging, based on the charging capability the method is faster compared with the other. Level 2 charger uses high power which is 3 to 5 times more than Level 1 charger which considerably reduces the charging time [17]. Level 2 charger with an AC supply of 208 V or 240 V provides power until 19.2 kW. In onboard charger special components and installations are required for transferring high power. Level 2 chargers employ a lesser charging time of 2-3 hours for charging 19.2 kW compared to Level 1 charger, the charging battery capacity ranges from 30 to 50 kWh [18]. The standard IEC62196-2 is followed by Europe and USA follows SAEJ1772 for charger connectors [19], [20].

Owing to the different parameters like weight, power and volume of first two level onboard chargers, the transfer of power takes either single/two directions. For the effective power flow, two stage topologies are used by onboard charger, in the front part rectifier and at the rear part DC chopper is used. The front part rectifier acts as a PFC linked to the grid feeding boost chopper. The battery is charged by DC chopper through a link satisfying load with a DC power. The charging time of onboard charger is more compared to offboard charger as a result of lower charging capability. The arrangement of onboard charger is manifested in Fig. 2. In the AC energizing station, the required power to the load is delivered through the charger by connecting rectifier to the source and the output in then fed to the DC chopper to obtain regulated power. The DC power is then delivered to the load with a proper protecting device. Many researches focus on modern control techniques to enhance the reliability, competence, grid support and controllability have been proposed [23].

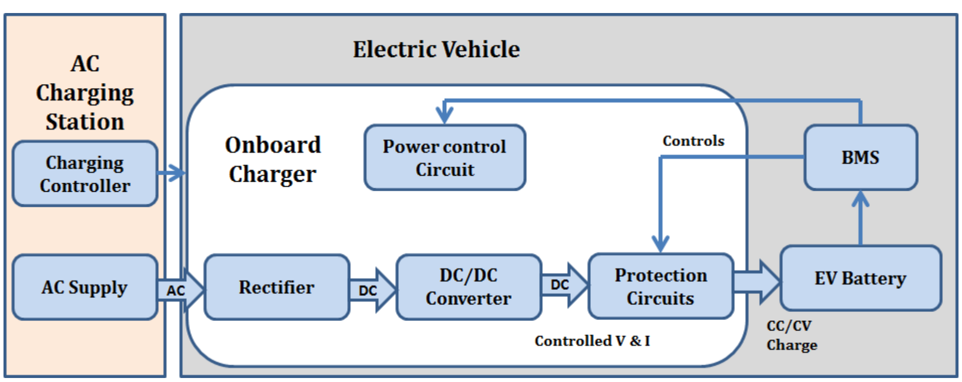
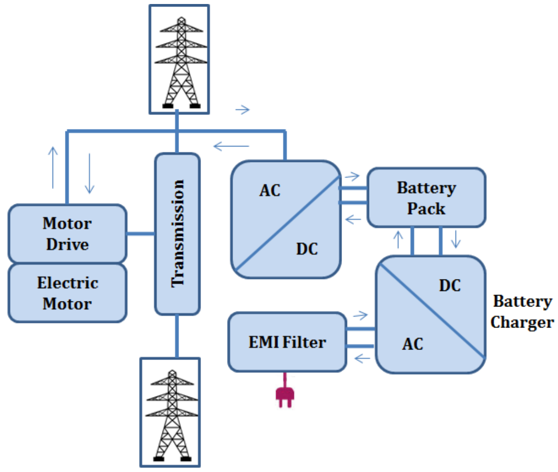


FIGURE 2
CONFIGURATION OF ONBOARD CHARGER

III. Dedicated onboard charger

The dedicated or conventional charger uses conditional output power, it is a self-sustaining device with a desire of energizing EV battery. The energizing system follows first two levels of energizing standards with a supply system consisting of single or three phase power which is designed small and lightweight. The supply power associated with the charger is in the range of 3.6 kW to 22 kW (supply of single phase and three phase). The supply to the charger is obtained by connecting the charger to the wall socket and the required load power is procured by connecting to the converters (AC-DC and DC-AC) in the onboard charger. IEC 61000 standards provide the solution for increasing the supply of quality power on the grid. Due to the limitations of weight and space in commercial electric vehicles, the AC charging is bounded to 22 kW. The challenges faced by the onboard chargers include voltage limitations of the battery, dependence of charging outlet, DC output can be restrained with AC voltage controller, incompatible ground reference. By adding components to the vehicle to improve the safety requirements at higher power levels the vehicle volume and heaviness increases. The devoted DC chargers with a power level of 22 kW are inducted at work location, residence, penthouse, and shopping complex. The economically available chargers comprises of two power converters for converting the power as required, it is attached to the supply system with an electromagnetic interference filter.
In the first stage, the required output to charge the load is obtained by connecting the supply to the rectifier and the output is the fed to the DC chopper through the link to satisfy the load requirement. The harmonics is limited by PFC comprised rectifier. The high power to the load is transmitted through inductor and capacitor (LLC). The grid frequency is filtered by connecting a capacitor of considerable size uniting two converters. The topologies of various onboard chargers are reviewed [24], [25], [26]. Major layout of conventional onboard chargers are diode bridge and interleaved PFC boost converters. The modern onboard chargers use interleaved topologies in the front end, according to General Motors evaluation [27]. The next generation volt charger comprises of four bridges and two boost converters which is interleaved is fastened to the grid with a halfway DC link of 400 V as manifested in Fig. 4(a). The DC-DC modification stage uses resonant LLC full bridge converter to gain output voltage.
The Tesla's modernized charger adopts almost identical DC-DC modification stage and unified channels in parallel are exposed in Fig. 4(b). The Tesla onboard charger with a energizing capability of 7.7 kW (32 amp) and 11.5 kW (48 amp) V3 superchargers are employed to charge the EV battery [28], [29]. For the protection of 32 amp onboard charger 40 amp circuit breaker and 18 amp onboard charger 60 amp circuit breaker is recommended [28]. Hyundai onboard chargers uses flow of power in two directions supporting vehicle to device application is shown in Fig. 4(c). To facilitate appropriate voltage for different configurations, the conductive charger comprises of AC-DC converter supplied from a single phase and DC chopper (buck boost) adhered by an active bridge with the flow of power in two direction [30]. The passive diode rectifiers are replaced by bridgeless boost type PFC topologies to bring down the modification stage and power losses [31]. Hella electronics introduced matrix type converter by reducing the conversion stages. The dedicated onboard charger by Hella electronics uses matrix converter which changes the frequency of the grid into midway frequency with substantial DC filter linked to the load as manifested in Fig. 4(d). The converter with rated power of 7.2 kW achieves a maximum efficiency of about 98% [32].



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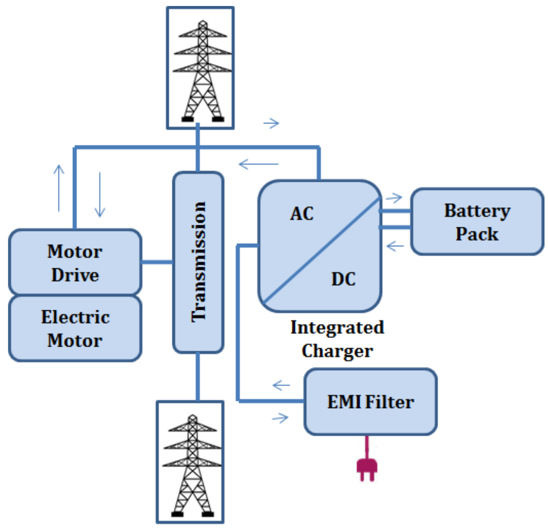


(b)

FIGURE 3
LAYOUT OF CONDUCTIVE CHARGER (A) ONBOARD POWER TRANSFER OF DEDICATED TYPE (B) ONBOARD POWER TRANSFER OF INTEGRATED TYPE

IV. Integrated onboard charger

To surmount the boundary of traditional onboard chargers the conductive onboard power transfer of integrated type have been employed without affecting the advantages of the existing conventional chargers like rapid energizing capability, diminished components, capacity of the charger and cost [34]. The modification stage with enhanced capacitor and inductor is avoided by using electric motor, converter for different stages of charging, and driving system. In addition to the advantages stated, the integrated charger offers high power in two direction and ample battery space [35]. The winding in motor provides electrical isolation and filter circulation and the inverter acts as a bidirectional converter [36], [37]. The current and voltage ripples in the integrated chargers are reduced by addition of supplementary components. Due to the presence of electric motor, traction controllers are employed as a result charging power is limited with the existence of zero average torque [38]. The induction motor drive and the combined battery charging system of integrated onboard chargers are designed by Renault and Ford charging company [39], [40]. The integrated chargers with switched reluctance motor or alternating motor is associated to the DC chopper through the link have been proposed [41]. The Renault Chameleon integrated charger with penetrative components for both the AC input supply employs power flow in one direction and blocks in other direction using one directional IGBT switch [42]. With the help of supplementary grid motor is interfaced without producing rotational force in the motor [43].

Valeo charger uses H bridge converter attached to the doubly excited motor winding supplying high voltage to the load connecting DC chopper to the H bridge. Continental high power onboard charger uses rectifier to convert AC-DC and additional components to get filtered output. Moreover, three phase voltage (400 V) and electrical isolation is possible at high power charging [44].

The multiphase rectifier coupled to the storage device has a decoupled inductor in the motor [46], [42] and [43]. During battery charging to accomplish traction mode over and beyond electrical isolation the motors is equipped with multiterminal this acts as a isolated integrated onboard charger. The stator winding of motor is fastened to the supply depending on the charging configuration. The integrated isolated bidirectional chargers utilized for single phase systems achieves fast charging with power factor similar to resistive load. Table II shows the commercially available onboard chargers with its specifications like supply of storage device, volume, energizing power, energizing time, and distance. For fast charging of electric cars high voltage batteries with voltage up to 800 V is utilized, in order to enhance the safety isolated high voltage system is added

The battery energizing system employed with solar PV allows slow daytime charging and wired charging at night time providing continuous charging framework with a budget friendly application. The dual charging feature makes the electric vehicle ecofriendly by employing renewable energy sources. The result of the photovoltaic rely upon the amount of radiation present in a day an varies with the climatic conditions. The infrequent supply power is compensated with the help grid connected system. Thus by integrating power from photovoltaic and grid connected approach the consistency in power supply is achieved without any interruption. With the aim of obtaining topmost benefit of the dual charging system it can be employed in locations like commercial buildings, parking area and workshops where the installation of photovoltaic can be made easier

V. Off Board Chargers

The offboard charger energizes a storage device utilizing commercial power source (in the range of 20 kW to more than 350 kW). Since the offboard battery charger is found external to the EV and hence the component cost, size, mass and volume of EV is reduced which provides feasible environment for faster energization of EV. In addition, for a broad span of battery supply i.e., from about 300 V–1000 V and above, the variable voltage control is required.

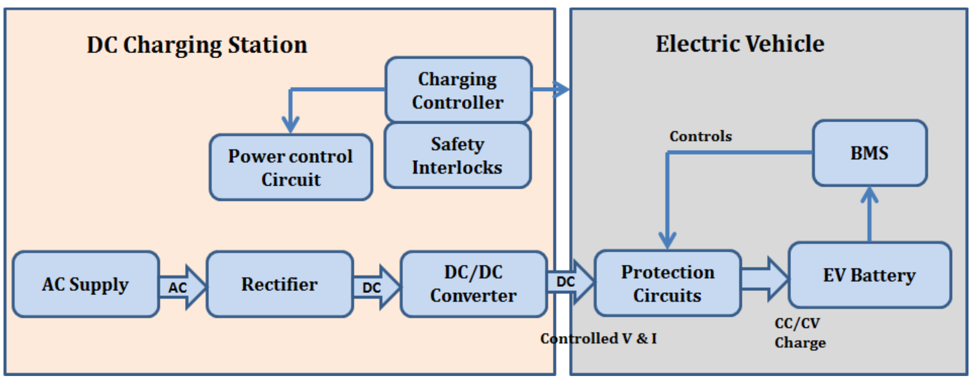
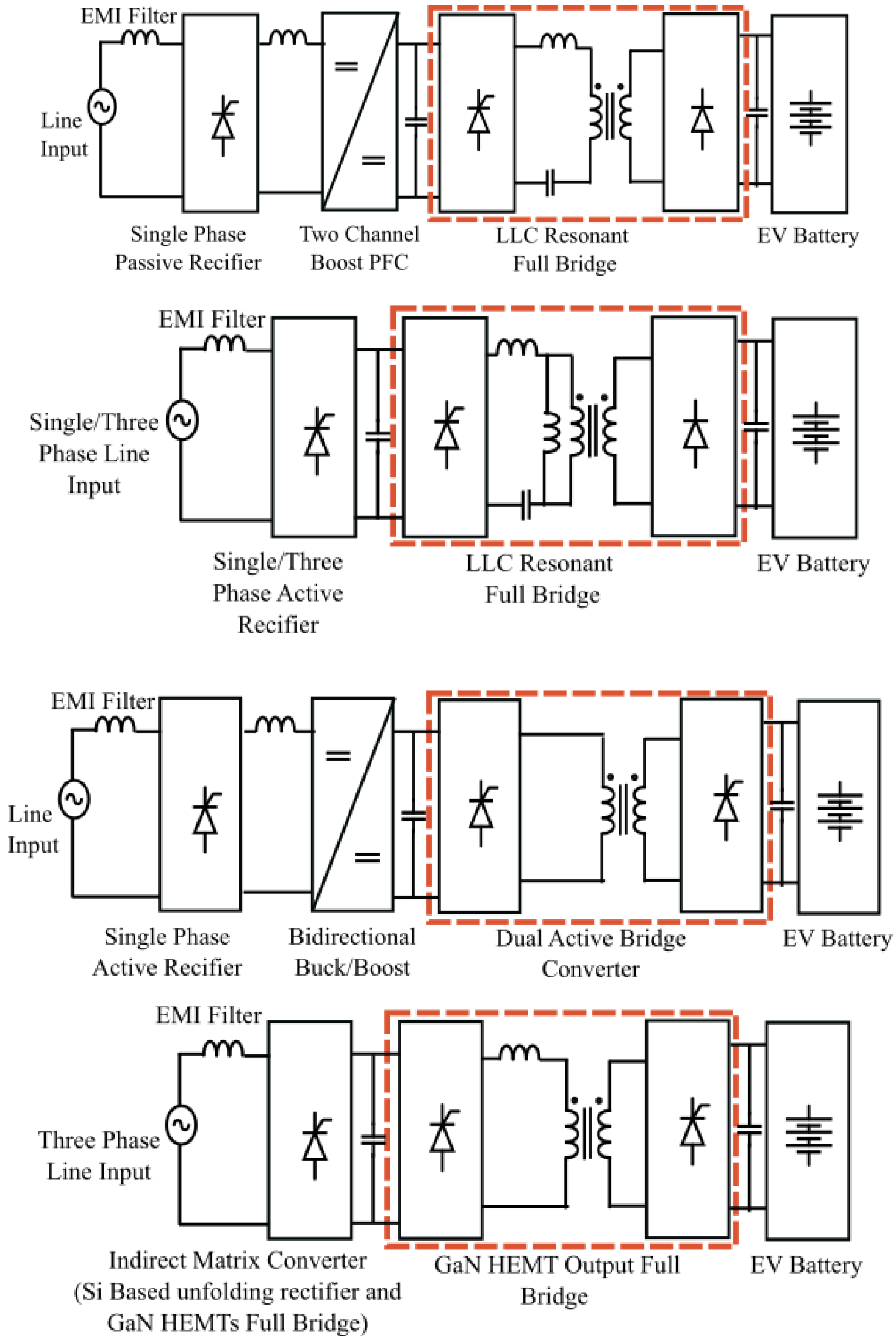


FIGURE 4
CONFIGURATION OF OFFBOARD CHARGER

The storage device is energized by both AC & DC supply in Level 3 or DC rapid charging at higher voltage. The offboard charger with a DC supply voltage of over 300 V to 800 V is used to deliver higher power ranging from 20 kW to 350 kW. Rapid DC chargers linked to the vehicle via charging inlet of offboard charger to power grid. The energizing time of Level 3 charger is in the range of 0.2 – 0.5 hours for a power of 90 kW which is faster compared to Level 1 and 2 [16]. Th first two-level low power chargers have lowest adverse effect on the network during maximum demand, whereas DC fast chargers may overload the local distribution grid with the use of high power during maximum demand [21].

Extremely rapid/fast charging (XFC) system provides a refilling background like Internal Combustion Engine vehicles with its capability of charging EVs at high power. The XFC system with a DC supply of 800 Vdc recharges a battery of power level over and above 350 kW in a time of 5 min approximately. The XFC system installation cost is very high which is intended with switching components concentrating on transformer of solid-state type (SST), DC chopper of isolated type, rectifier and regulators to deliver high power. To reduce capital investment and lower operational cost several XFC systems can be combined to make it financially achievable. In addition, SST brings the advantage of transforming the voltage from one level to the other (medium to low) providing electrical isolation in XFC [22].



(a)

(b)

(c)

(d)

FIGURE 5

CONFIGURATION OF ONBOARD CHARGER OF DEDICATED TYPE (A) NEXT-ORIGINATION VOLT CHARGER (B) TESLA FAST CHARGER (C) HYUNDAI CHARGING MODEL (D) CHARGING MODEL BY HELLA ELECTRONICS

TABLE I
DISTINCTIVE CHARGING LEVELS OF ELECTRIC VEHICLES

Specification	Level 1	Level 2	Level 3	XFC – Extreme Fast Charging
Charger Power	1.44 kW – 1.9 kW	3.1 kW – 19.2 kW	20 kW – 350 kW	>350 kW
Charger Type	Onboard – Slow charging	Onboard – Semi fast charging	Offboard – Fast charging	Offboard – Ultra fast charging
Charger Location	Residential	Residential and workplace	Commercial	Commercial
Charger Time	200 km: +/- 20 hours	200 km: +/- 5 hours	160 km: +/- 30 min	Approximately 5 min with high energy density
Power Supply	Voltage:120/230 V, Current: 12-16 A, Supply: Single phase AC	Voltage:208/240 V, Current: 12-80 A, Supply: Single phase /Split phase AC	Voltage: 208/240 Vac & 300-800 Vdc Current: 250-500 A, Supply: DC and Three phase AC	Voltage:1000 V and above, Current: 400 A, Supply: DC higher polyphase
Protection Type	Breaker in cable	Breaker in cable and pilot function	Event monitoring and communicating between EV and Charging station	Event monitoring and communicating between EV and Charging station, liquid cooling
Standard	SAE J1772, IEC 62196-2, IEC 61851-22/23, GB/T 20234-2		IEC 61851-23/24, IEC 62196-3	IEC 62196, SAE J2836/2 & J2847/2

TABLE II
SPECIFICATION OF COMMERCIAL ONBOARD CHARGERS [33]

Model and Manufacturer	Battery Capacity (kWh)	Charging Power (kW)	Battery Voltage (V)	Charging Time (Minutes)	Distance (km)
Model S, long range - Tesla - 2022	100	200	400	24	624
Model 3 Performance - Tesla - 2021	79.5	120	360	33	567
Bolt EUV - Chevrolet - 2022	65	50	350	66	402
Leaf SL - Nissan - 2019	62	100	360	35	346
Leaf S - Nissan - 2019	40	50	350	36	378
Ioniq 5 Long Range - Hyundai - 2022	72.6	160	800	18	412
e-208 GT - Peugeot - 2019	50	100	400	30	450
Taycan 4S - Porsche - 2022	79.2	225	800	21	407
MX - 30 - Mazda - 2021	35.5	50	355	34	265
e-tron 55 Quattro - Audi - 2022	95	150	396	26	441
Q4 Sportback 55 - Audi - 2022	82	110	400	38	460
i4 M50 - BMW - 2022	83.9	210	398.5	31	510
iX xDrive50 - BMW - 2022	111.5	195	330	35	630
RQS 350 - Mercedes Benz - 2022	90.56	170	500	30	626
I-Pace S AWD - Jaguar - 2020	90	100	388	43	470

VI. Battery switching

Battery switching technology plays a key role in electrifying heavy duty internal combustion vehicles into an electric vehicle. The extensively used energy charging type face the problems of consuming long time for energizing and lower transportation competence with regards to heavy duty EVs. In order to boost the efficiency battery swapping is considered. When the usage of charging station is more than 43% and the speed at which the automobile operates beyond 31 km/h, the battery switching is the cheapest technique for energizing heavy electric trucks [45]. The efficient recharge distance for swapping is 156km. By virtue of insufficiency in the accessibility of resources like energizing stations, energizing delay, pressure in the service grid and inherent EV range anxiety in the current EV owners. The acceptable solution for the above-mentioned problem is the conductive charging (transfer of power is carried out with a conductive link between the station equipment and battery), inductive charging (transfer of power is carried out without any conductive link between the station equipment and battery through the principle of induction), and the battery switching system (discharged batteries are restored by a completely charged one) [47]. Based on the advancement in the current field the power transfer of conductive and inductive type are preferred mostly and the battery switching system is the least preferred one, has still not disposed as a possible choice. The promising solution for the current scenario is the battery switching. The following key benefits are adopted in battery swapping than other methods faster energization of EVs. The work is easier like internal combustion vehicles, where the car is driven to the station, locate the vehicle in the area allotted, once the task is complete by making payment the car can leave the station [48-50]. Due to the quicker operation than refueling an internal combustion engine, the entire process takes only few minutes to complete the process. These results in serviceability and adaptability of EVs compared to internal combustion vehicles. Based on the above-mentioned advantages electric mobility is preferred [51].

VII. Battery swap station challenges

The major advantage of the switching station is the rate at which the swapping is done, where the entire process takes fewer than five minutes. Today for the same time gas tanks are filled at gas stations. Another advantage is that driver need not have to leave the vehicle during the operation and also need not deal with dirty or angled cords. Here are some of the difficulties related to implementation of battery swap station they are battery degradation, battery ownership, charging infrastructure, interchangeability and feasibility as shown in Fig. 6 [52].

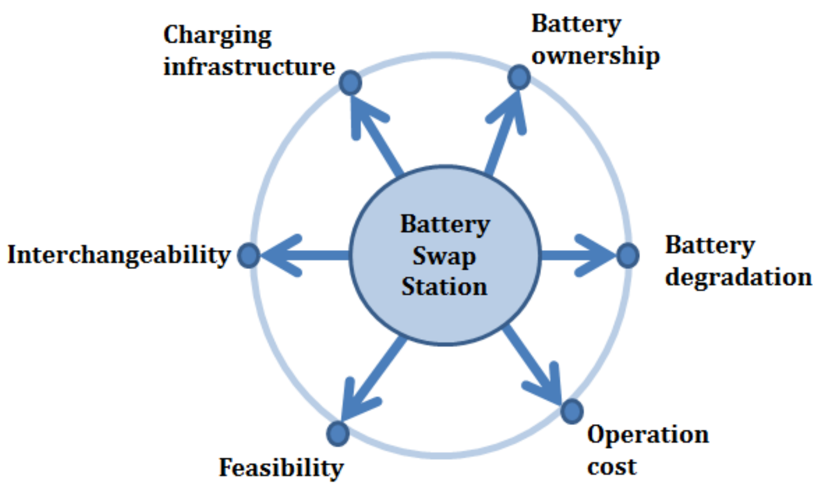


FIGURE 6
CHALLENGES OF BATTERY SWAP STATION

VIII. Interchangeability

Interchangeability of batteries is the best solution for fast charging without any delay in charging like internal combustion vehicles. The technique is possible only when the different manufacturer manufactures similar battery packs as a major option. The feature is fully reliant on the manufacturers' decision, which may also lead to the following limitations innovation of product design, flexibility, uniqueness, innovation in design as cell manufacturers. The manufacturer standing among the highest design also have to provide a design of standard cell to supply similar cell in market, only standardized products to be produced. This may lead to compatibility issues due to supply and demand with vehicles [52], and [53].

IX. Feasibility

The battery design plays an important role in swapping battery technology. The design requirements should follow removing and reinstalling it from the electric vehicle. The battery design offers swapping of battery only in few electric vehicles in India. The swapping feature offered by Hero Maxi permits drained battery to be switched with energized one and the storage device can be energized individually [52], [54], and [55].

X. Infrastructure

The battery packs are expensive than charging. The system is complex in designing a swap station to provide continuous charging of battery and swapping. The demand is similar to energizing the storage device, but the difference is the need can be controlled. The battery packs for the incoming customer should always be available and hence charging time to be offered accordingly. The charged battery packs should always be greater than that of the percentage of daily demand. The battery demand can be overcome by keeping additional battery for each EV one enclosed by EV and another battery at the switching station. Considering the economics in implementation of battery switching system it is not really favored [56]. Fig. 7 shows the infrastructure for both charging and swapping mode of electric vehicles

XI. Battery degradation

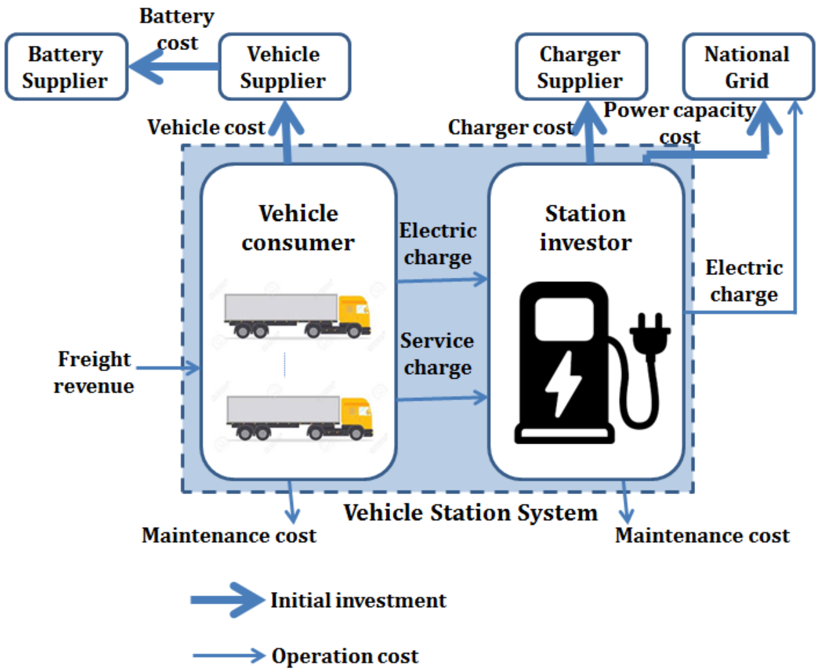
Owing to ageing of battery packs it offers lower storage of energy caused by deterioration of long-time battery usage and will affect the serviceability of EVs. Hence the users will prefer new storage device than older one, which leads to the reduction of operating cycle of any battery packs. However, the fully energized battery impacts unfavorably by the deterioration with adaptation over a period of time [57].

XII. Battery ownership

In this case the EV user needs to acquire two batteries one to keep it on the vehicle and other can be used as a replacement battery. This will result in claiming null ownership over the battery of EV. It offers the following advantage since the ownership cannot be claimed by the owner, the EV users need not pay for it which leads to cheaper EV.

XII. Operation cost

The vehicle owner never gets the swapped battery and the ownership is null. In addition to the cost of energy the owner has to pay the lease amount. It can be charged for each swapping or at a particular frequency for a period of one month. The later lease amount method is costlier including service charge and minimum two battery packs. The lease for each swapping is also costlier which leads to less usage of swapping stations [58].



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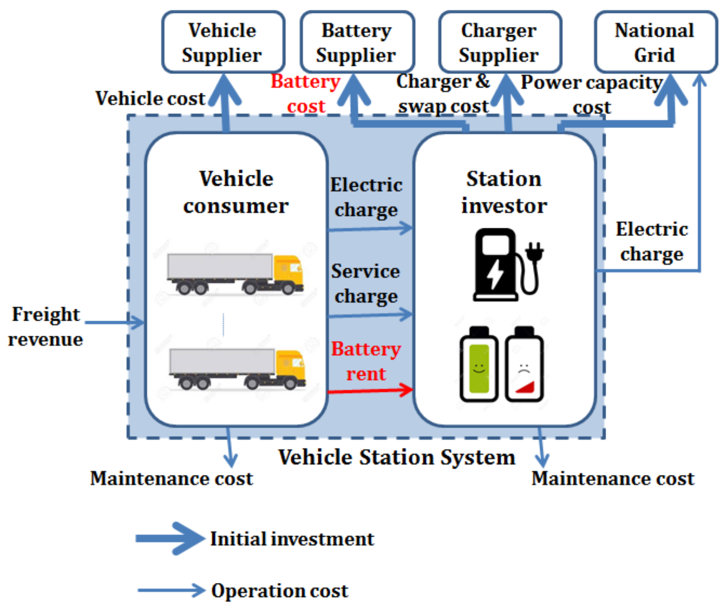


(b)

FIGURE 7
CASH FLOW DIAGRAM [47] (A) CHARGE MODE (B) SWAP MODE

In charging system, the initial investment cost includes charger cost and cost of power capacity on the station investor side, whereas on the vehicle consumer side the cost includes battery and vehicle cost. The operation cost includes maintenance and electric charge on station investor side, similarly electric charge, service charge, freight revenue and maintenance cost on the vehicle consumer side is shown in Fig. 7(a). The battery swap station needs proper planning to provide charged battery based on the demand. It increases the initial investment cost of setting swap station. On the vehicle consumer side additional battery rent will be charged for each swapping. The operation and the investment cost are shown in Fig. 7(b).

XIV. Wireless charging

The efficient performance of electric vehicle requires fast, reliable and economic charging system. The cordless charging system provides energizing EVs without connecting the device to the plug compared to conventional conductive charging methods. The cordless charging brings down the conduction losses where the use of wires, instinctive connectors and the associated framework are non-compulsory. The wireless charging can be adopted using capacitive, inductive and resonant inductive [61]. Conductive or plug in chargers provide EV owners trouble in connecting high voltage batteries to the cords until the batteries gets charged completely. The problem can be rectified my implementing wireless charging, as a result it improves EV performance. Fig. 8. Manifest the cordless charging technology for electric vehicles. The main issues in implementation is limited power transfer capability and initial investment cost.

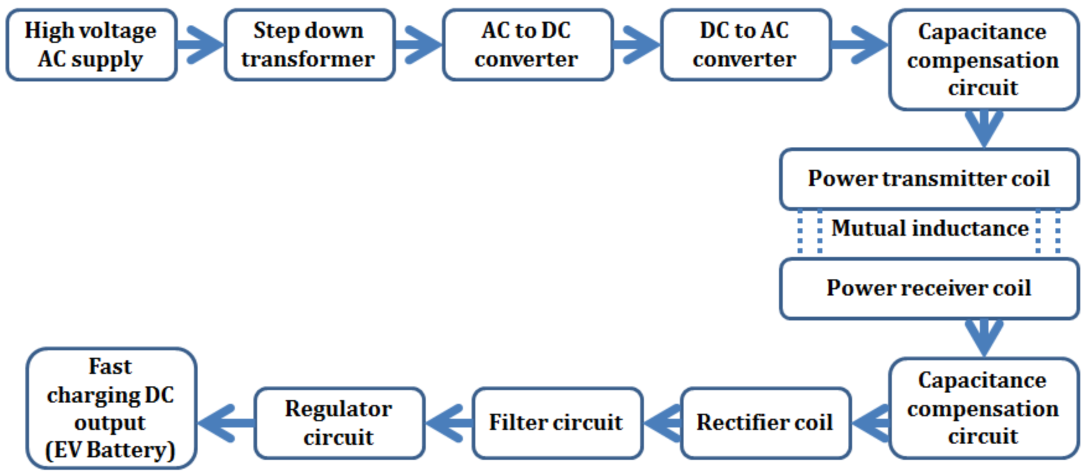


FIGURE 8
WIRELESS CHARGING TECHNOLOGY

To avoid safety hazards the standards by regulatory bodies to be followed. The new era of cordless power transfer provides the ability towards cordless charging with the innovative research and development in power transfer capability of wireless charging technology [62].

XV. Capacitive charging

The capacitive wireless charging technology or medium and low power transmission technology is used in spinning machines [65], phone chargers [67] and portable electronics [66] due to the ease of use, mechanical configuration and geometric pattern of coupling capacitors [63] and [64] provides the advantages as mentioned. Instead of wires, AC coupling are used for the power flow between source and battery. The half bridge converter is connected to the supply with a separate power quality control circuit. The high frequency AC supply generated from the H-bridge is transmitted on the receiver's side through the coupling capacitor. The schematic representation of the capacitive wireless charging technology is presented in Fig. 9.

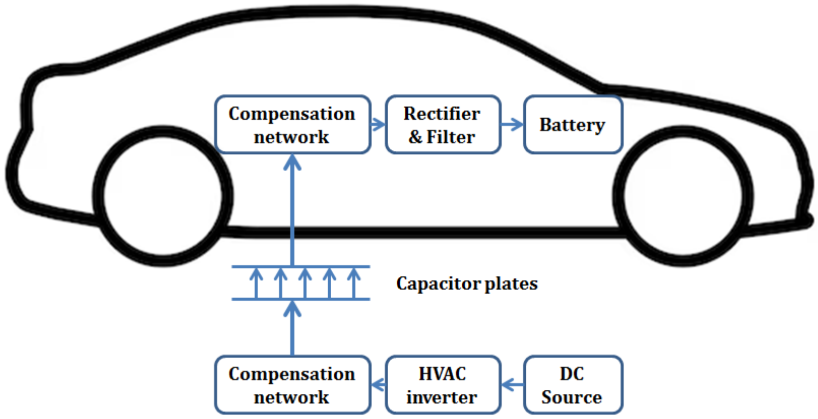


FIGURE 9
SCHEMATIC REPRESENTATION OF CAPACITIVE CHARGING

The energizing runs on both maximum and minimum current. Hence to lower the values of impedance during transferring and collecting at the composition of resonance, extra inductor should be added with the coupling capacitors. With proper rectification and filtering components the AC power can be transformed to DC as required by the load or battery bank. The power transfer capability can be improved by controlling the two variables first one is capacity of the coupling capacitor and secondly spacing through the capacitor plates. The excellent performance of capacitance charging is offered by restricting the smaller air gaps between the capacitor plates. On account of the power demand and air gap the capacitance charging is applied partially to the electric vehicles. The suggestions on reducing the air gap and high capacitance rotary mechanism design are offered [68]. The air gap through the capacitor plates can be reduced by connecting a receiver to the bumper bar of the vehicle. The model will supply a power of 1 kW to the load with an operating frequency of 540 kHz at 83% efficiency is developed. The expulsion current created by diversified electromagnetic fields is liable to transferring power wirelessly bounded by transferring and collecting power. In place of magnets or coils, for power transmission coupling capacitors are prone to both transferring and collecting power through wireless transmission [69-75]. The power factor should be maintained to enhance the competence, voltage level and to bring down transmission losses using power factor improvement circuit. Due to the electrostatic induction principle, the high frequency AC supply is given to the transmitting plate after compensation, which in turn produces displacement current at the receiving plate. The received AC voltage is improved by passing it to a half bridge. The AC voltage is transformed into DC using rectification and filtering components to energize the storage device based on battery management system. The supply parameters like voltage and frequency and the component dimension, size and the air gap in which the coupling capacitor is placed is responsible for power transmission between the transmitter and the receiver. The frequency lies between 100 to 600 kHz [60].

XVI. Inductive charging

The traditional inductive power transmission for wireless transmission was developed by Nikola Tesla in 1914. The visual representation of inductive power transmission is presented in Fig. 10. Based on the idea several wireless charging techniques are followed. The cordless power transmission from the supply to the receiver is carried out ranging from MW to KW. Chevrolet S10 EV in 1996 used magnetic charge inductive power transmission to feed with two power stages slow charge of 6.6 kW and rapid charge of 50 kW [76]. The vehicle is charged by inserting an inductive coupler into auto charging port to receive energy on the secondary coil. The EV charger with a power of 6.6 kW, 200 V- 400 V supply, 77 kHz running frequency charging was displayed by the University of Georgia. The magnetic induction principle plays a major role in transmitting power wirelessly using magnetic field linking transferring and collecting power through the coils [77-83]. When the supply is passed to the transfer coil, the magnetic field is established around the coil and when the collector coil passes through it the AC power is created by the transportation of electrons. The car battery is charged with the converted and filtered AC output. The parameters to be monitored for effective power transmission are frequency, the induction between two circuits and the separation between the coils. The frequency range of inductive charging is 19 to 50 kHz

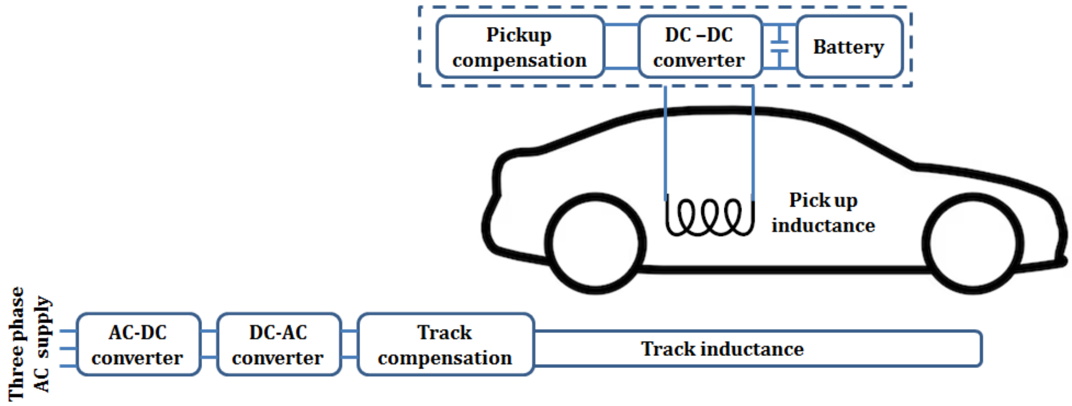


FIGURE 10
INDUCTIVE CHARGING TECHNOLOGY

XVII. Resonant inductive charging

In resonant inductive charging resonant condition is used to transfer power effectively in case of inductive wireless charging. Owing to the weaker magnetic fields in inductive charging to transmit power at much higher rate, the resonant operation with excessive elements makes switching equal amount of electricity. The advantage of wireless power transmission includes transmission of power over larger distance without the use of cables. The power transfer occurs only when the resonant frequencies of transmission and the reception are coordinated to fulfill the above said condition [84-87].
The components are appended in such a way it provides same or different current to achieve appropriate resonant frequency. With the raise in resonant frequency due to the addition of extra components helps in reducing additional losses. The operating frequency of resonant inductive charging ranges 10 to 150 kHz [60].

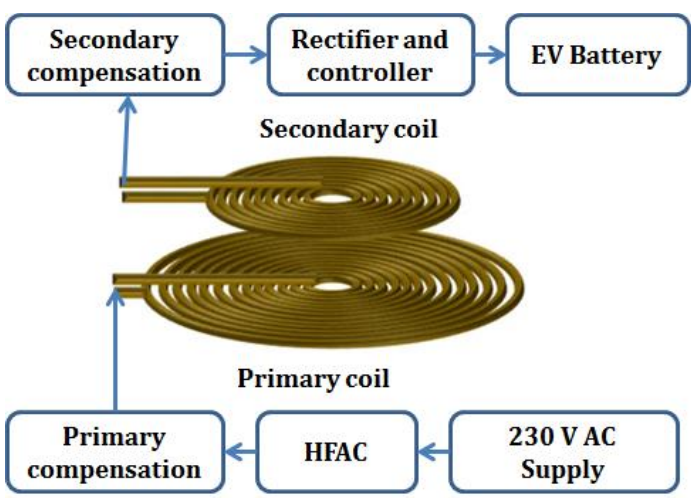


FIGURE 11
WIRELESS CHARGING TECHNOLOGY

STANDARDS OF ELECTRIC VEHICLE CHARGING

The standard is a legal document/ chronicle bloomed by the specialist from various countries that is validated and disseminated by a globally recognized body which lays foundation for customer satisfaction and broad market penetration. Due to the increased usage of EVs, it creates new challenges and requirement to achieve the same outcome again and again. In order to maintain uniformity certain processes, rules, guidelines and characteristics are formed by the experts and are agreed globally. International charging standards are applied to resolve reliability, accuracy, protection, interoperability and integration issues of EV industry [96], [97]. The industries concerned with vehicle manufacturing and charging include the listed manufacturers battery, vehicle component, utility companies, battery switching station, service technicians, insurance companies, providers of EV charging, and electrical inspectors should follow the policies framed as per international standards. The various standards are formed by different association as listed in Table III. The standard Society of Automotive Engineers (SAE) provides the framework for energizing and integrating to the grid. The conductive charging is infrastructure is furnished by International Electrotechnical Commission (IEC) standards. The various charging standards include conductive charging, wireless power transfer, grid integration and safety. The components used in planning energizing stations should follow certain rules and instructions to assure safety while charging [98].

Based on different criteria IEC developed various charging standards as follows

- To ensure safety on conductive charging without affecting household and similar electrical appliances
- Electric vehicle power transfer through wireless charging
- Conductive charging components plugs, vehicle connectors, socket outlet and vehicle inlet
- The driving force of electric vehicles can be analyzed using secondary lithium-ion cells
- Low voltage electrical installations
- The vehicle-vehicle-grid communication is carried out using version control management
- Electromagnetic compatibility

Table III shows some of the standards to be followed when constructing an EV and mounting energizing station. The standards SAE J1772 provides the specification for components of conductive charging like connectors, plugs, socket outlet and inlet. The connectors in AC and DC charging of EV are provided by IEC 62196 and IEC 61851 standards. The standard for wireless or cordless charging is given by IEC 61980. IEC 62840 standard offers the specification for swapping battery in a charging system [99].

The IEEE standard leaves way to the plan of EV and DC rapid energizer that encourages various features like better performance, component safety, conductive charging, cordless charging, interoperability, testing methodology and so on [100]. The revised standards with additional functionality, design requirements and technological advancements are included to improve the uniformity. There are various IEEE standards which include for grid connections, wireless power transfer and charging standards, interoperability of the grid, structure for electric transportation, harmonic control in power system and so on are listed in Table III.

The charging system comprises of two kinds of energizing which include AC and DC supply for energizing system. In Japan and USA, the domestic supply voltage of 100 V is used and in Europe the supply voltage of 220 V AC is used to charge the battery as per SAE J1772. The component safety features like connector, ports, inlet and outlet are designed using different standards like IEC62752, CHAdeMO-C601, NFPA70B, UL2251, 2202, 2594, 1741, and ANSI/UL2594 [101], [102]. The grid integration standards help in controlling the energizing and reenergizing of EV all over the grid. The standards have an eye on the following terms regulating power, safety features, supply quality power and the code to encounter assimilation of EV to the grid. The standards are established by various organizations include IEC, IEEE, ISO, UL and NFPA organizations.

The safety, performance, maintenance and testing of the grid interconnection on the distributed system is included in IEEE 1547 [90]. UL 1741 standard provides the safety feature for power converters, and controllers [103]. The interoperable control of EVs with the test procedures, response specifications, security requirements and information standards are provided by the communication standards ISO 15118 [104].

To ensure safe and appropriate supply to the battery and electric vehicle performance the standards are categorized under two categories as electric vehicle standards and battery standards. Among the battery standards are considered under the following category battery testing methodology, performance and power rating, battery swapping and so on. Under the category of electric vehicle standards conductive charging, wireless charging, fuel safety, fuel economy, power/ range, component safety, grid communication and charging standards are developed to regulate the performance of the devices. The safe power supply between EV battery and energy source is ensured by delivering appropriate power to the EV. Therefore, to extend the safety needs standards are evolved for communicating between devices. The safety standards and technical regulations of battery pack and high voltage standards is developed by standard organizations like International Organization for Standardization (ISO), SAE, and IEC [105].

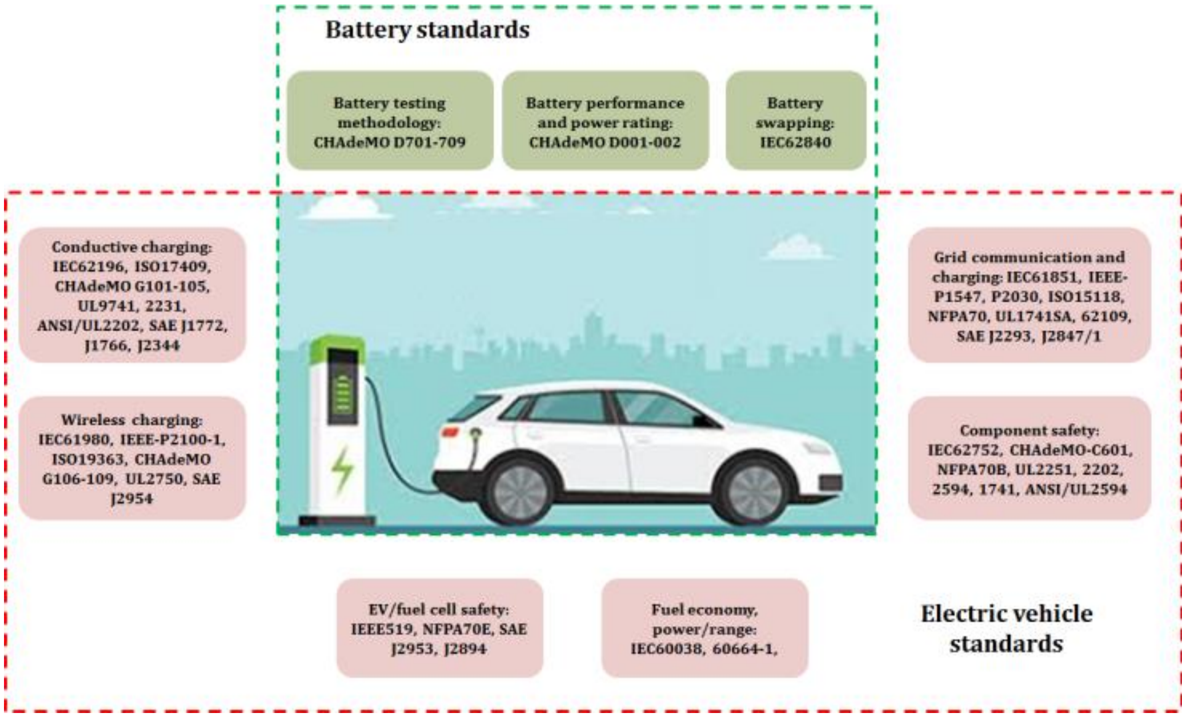


FIGURE 12
STANDARDS FOR EV AND BATTERY CHARGING

TABLE III
STANDARDS FOR EV CHARGING STATIONS

Organization	Standards	Description
IEC [77]	60038	Standards for the voltage of charging applications
	62196	Standards for EV conductive charging components (plugs, connectors, inlets and outlets)
	60664 - 1	Installation coordination for charging equipment in low voltage supply
	62752	Standards for cable control and protection devices
	62840	Standard for battery swapping charging system
	61851	Covering safety related specifications on the charging stations
	61980	Wireless power transfer for EVs
IEEE [78]	P1547	Standards for different aspects of grid connection s
	P2100,1	Wireless power transfer and charging standards
	P2030	Standard for addressing the interoperability of smart grid
	P2030,1	Draft for electrified transportation structure
	519	Requirements for harmonic control in electrical power system
ISO [79]	15118	Standards for vehicle to grid communication protocols and interfaces
	17409	Specifications for the connection of EV with an external energy source
	19363	Safety and interoperability requirements of EVs - magnetic field wireless power transfer
JEVA (Japan) and CHAdeMO [80]	C601	Charging plugs and receptacles
	D001-002	Battery characteristics of EV
	D701-709	Instructions for battery testing
	G101-105	Fast charging standards
	G106-109	Wireless charging standards
NFPA [81]	70	Safety standards for grid integration
	70B	Contains safety measurement for electrical equipment
	70E	Electrical safety standards in workplace
UL [82]	2231	Requirements for protection devices of EV charging circuits
	2251	Requirements for charging plugs, receptacles and couplers
	2202	Requirements for charging system equipment
	2594	Requirements for EV supply equipment
	1741	Specifications for inverter, converter, charge controller and output controllers used in power systems
	1741 SA	Defining safety requirements of inverters for grid stability
	62109	Safety requirements of inverters used in grid-connected photovoltaic system
	2750	Outline of investigation for WPT equipment
	9741	Bidirectional EV charging equipment
ANSI/UL [82]	2202	Electric vehicle charging equipment
	2594	Electric vehicle supply equipment
SAE [83]	J2293	EV and off-board EV supply equipment requirements for charging from utility grid
	J1772	Conductive charger coupling of AEVs and HEV
	J2953	Standard for interoperability of EV and charger
	J2954	Wireless power transfer for electric vehicles
	J2894	Power quality requirements
	J1766, J2344	Safety requirements for charging
	J2847/1	Communication between EV and the grid

FUTURE ROADMAP, ADVANCEMENTS AND CHALLENGES

The environmental impacts, economic growth, and social development led to the growth of EV have created advancements in electric transportation system also challenges on distribution grid. The major focus of EV industry depends on the following constrains charging time; EV battery related issues, distance coverage, high upfront costs and enhance charging facilities [106]. Therefore, to find the novel solutions of the existing issues it is important to explore control strategies, future developments and emerging technologies in the existing area. The manufacturers aim to launch connected and automated vehicles due to their low operating costs. For long range EVs rapid energizing with power of 100 kW to 200 kW is required. To meet the consumer, demand the manufacturers started to develop extreme fast charging beyond 350 kW to charge 80 % of the battery with less than 15 minutes [107]. The ultra-fast energizing of green energy vehicles increased the electric vehicle usage by providing the proficiency similar to the internal combustion vehicles at gas stations. In addition, by reducing the operating cost and charging cost improves the performance without compromising the fulfillment and meets customer expectation increasing the use of electric vehicles further. Automated vehicle offers a greater advantage including all the features in the same design.

The cordless charging are safe, reliable, flexible and cost-effective charging methods. The wireless charging method offers various advantages like reduced components, automated charging capability, less maintenance, and extreme fast charging. Owing to the advantages the cordless power transfer is preferred. The smart energy control to equipoise consumption and production enhancing the grid during demand the solutions are ready with V2G technology to reach the market. The growing demand of electricity is improved with the designed intelligent algorithm to improve the electrical network is another revolution of future EV technology [108].

Based on the data and previously available information the performance of the charging system can be improved predicting the future states with the help of the intelligent modules present. The dynamic and complex problems of EV batteries are addressed by the intelligent methods of the Battery Management System [109], [110]. For the implementation of intelligent transportation system, the information is exchanged as a consequence of internet of vehicles. The automated green energy vehicles require communication technology to improve transportation by including carious features like parking assistance, energy saving, reducing traffic maintenance and effective vehicle maintenance [111], [112]. The battery features are improved by concentrating on battery storage system, charging and discharging methods, SoC estimation and charging density of the battery. The size of the module is reduced by replacing silicon switches with power electronic devices [107].

The fear of driver to achieve the destination point with the available energy and search of charging station as a result of insufficient energizing stations is the major problem. The recharging time of the EV to be reduced alike fueling up of internal combustion vehicles. The innovative design and large batteries are used to achieve the difficulties, leading to increase in charging expense and the price of EV. The research focuses on reducing the fear of range anxiety in the future with the developments in economic and technical challenges. In order to enhance the usage of EV the energizing time plays a significant role, the rate of charging depends on the following factors battery size, SoC estimation method and charging time [113].

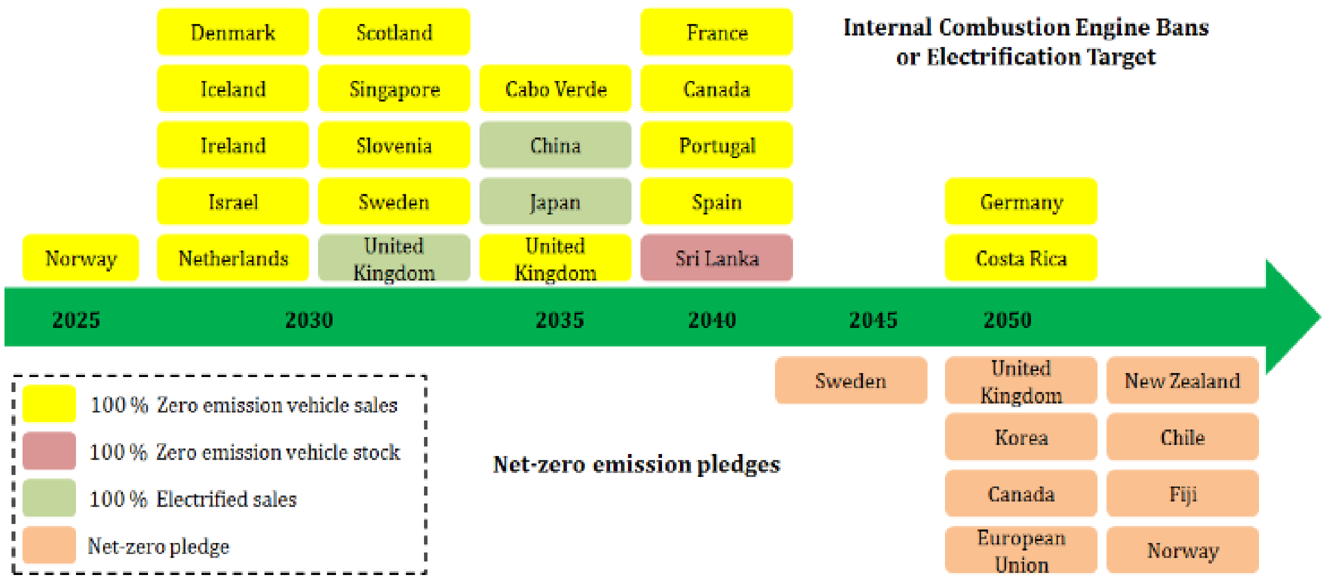
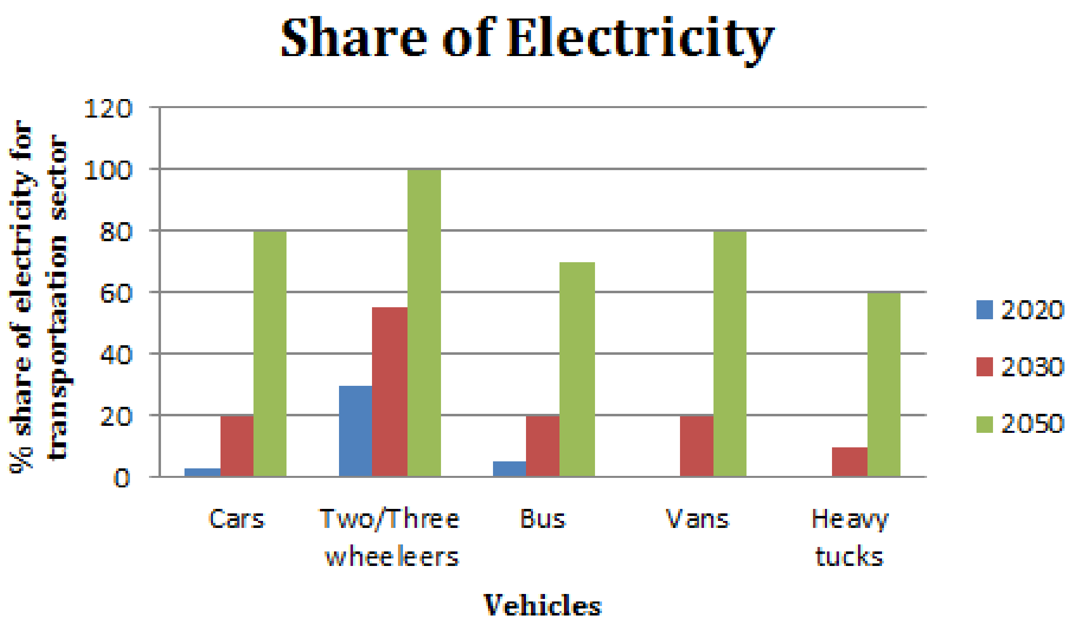


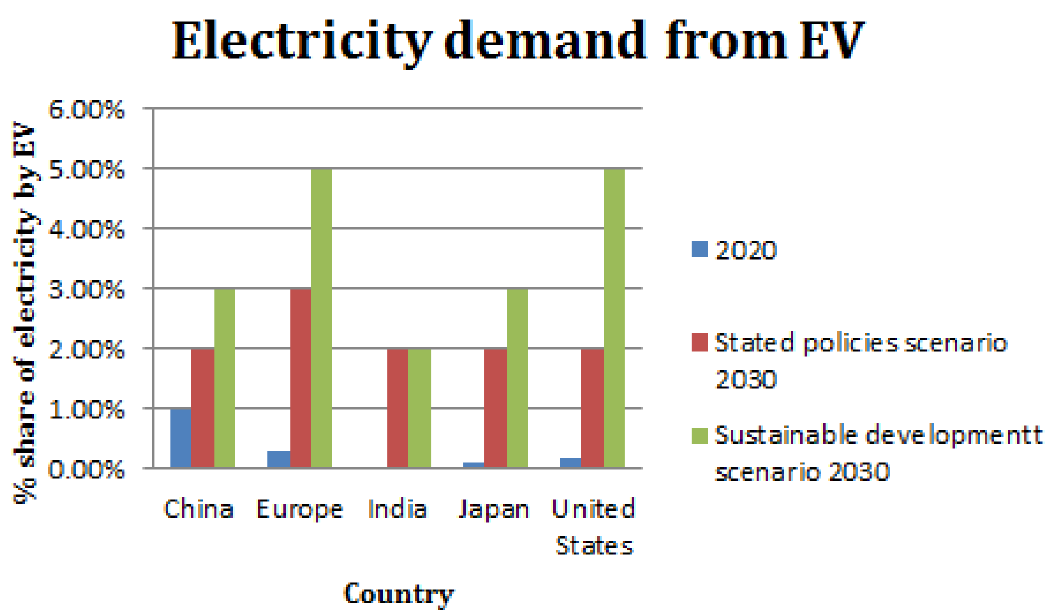
FIGURE 13
FUTURE ROADMAP OF NET ZERO EMISSION AND ELECTRIFICATION TARGETS OF DIFFERENT COUNTRIES [114]

The ambitious policy to accelerate the transition from internal combustion vehicles to EV mainly reduces CO_2 emission in the atmosphere. As per the study made by the international energy agency, there will be gradual increase in green energy vehicles and will reach its peak by 2050. Fig. 13 Shows the target framed by different countries to achieve net zero emission by increasing numerous amounts of automobiles on road by 2050 [116].

The electricity consumed for two/three wheelers in China is around 80 TWh in 2020. The demand is projected to increase by 525 TWh in 2030. The electric mobility results in electricity demand with the development in green energy vehicles. The future forecasting of electricity demand is calculated to satisfy the demand for electricity. Fig. 4. Shows the demand of electricity based on different countries and vehicles.



(a)



(b)

FIGURE 14
SHARE OF ELECTRICITY BETWEEN (A) VEHICLES (B) COUNTRIES [116]

The use of electric vehicles reduced emission of greenhouse gases globally by reducing CO_2 in the atmosphere of about 50 Mt in 2020. It is mainly achieved by electric two/three-wheeler fleet from internal combustion vehicles in China. The reduction of greenhouse gas emission is possible by expanding fleet of EVs and the reduction of internal combustion vehicles energized by natural fuels. This is implemented with an idea that electricity generation will reduce the carbon intensity to a greater extent than natural fuels. The need for electricity can be encountered by generating electricity in terms of decarbonizing methods, which results in mitigation of GHG emission.

The greenhouse gas emission of each country is determined by the dependence of carbon for power generation and the nonconventional energy usage to satisfy the electricity demand. As a result of reduction of greenhouse gases, based on the state policies the dependence of carbon for power generation is reduced by 20% and the sustainable development by 55% in 2030. It is possible only when the EV fleet were powered instead of internal combustion engine vehicles [116]. Fig. 15 shows the greenhouse gas emission reduction target by transportation sector for different year. The nonconventional energy sources are employed widely to energize the battery to satisfy the demand. By controlling the nonconventional energy sources integration on the grid and intermittency nature, the impact can be reduced [117]. The energizing and reenergizing capability of EV is improved by employing appropriate control strategies and the impacts on the grid are mitigated [118], [119].

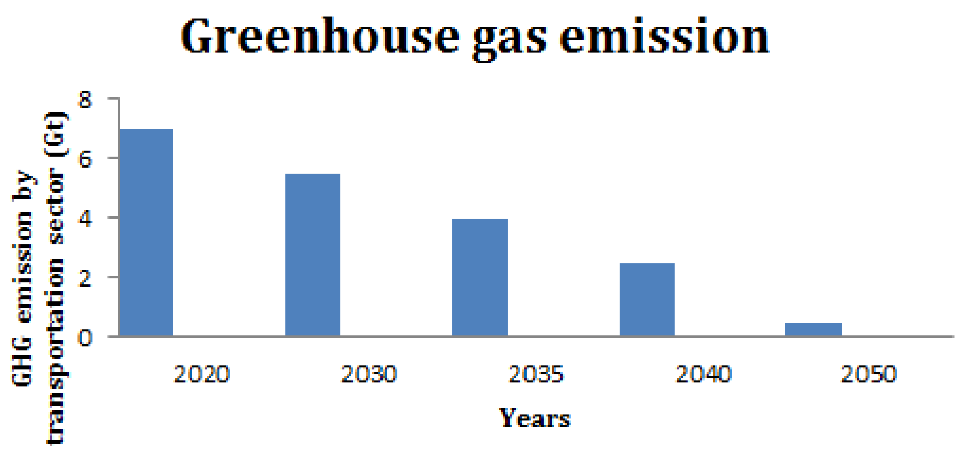


FIGURE 15
DEDUCTION PLAN OF GREENHOUSE GAS BY TRANSPORTATION SECTOR [97]

CONCLUSION

In this article, a summary of energizing EV based on different energizing methods like onboard charging, offboard charging, battery swapping, wireless charging, standards and future roadmap of net zero emission is demonstrated. With a focus of reducing greenhouse gases, the transportation sector increases the use of EVs to a greater extent than the internal combustion vehicles. Hence the dependence of fossil fuel as a primary source of energy is reduced. As a result the global warming and climatic change is improved to a greater extent. The broad implementation of EVs as a major choice provides a positive impact by bringing down the dependence of fossil fuel, and nonconventional energy usage for power generation, resulting in the deducting carbon emission.

Instead of internal combustion engines, electric motors are used as an alternative which offers the following advantages low noise levels, low operation and maintenance costs and extremely efficient. Despite the shortfall of charging infrastructure, the EV usage on road is increasing it commutes the EV usage to short distance trips. The current liquid and gasoline driven refueling infrastructure is to be replaced by cost effective charging system. The successful adoption of EV lies in the organized charging framework, sharp control design and intensified battery technology. The battery performance relies on the nature of charger, energizing and reenergizing groundwork, SoH and SoC assessment. The charging of electric vehicles is carried out by two kind of energizing one is AC charging station and the other is DC energizing station. Two main factors are considered while installing charging stations which include charging cost and charging time. DC fast charging stations are preferred by the automobile manufacturers due to less energizing time to energize the storage device with higher power capacity. Installing AC charging station is lesser compared to DC charging station, the DC supply offers fast charging hence DC is preferred.

According to the emerging technology the charging methods to charge the battery like wired charging, cordless charging and battery switching are discussed. The wired charging topology is split into onboard and offboard charger. Due to the advantages offered by the integrated chargers it can surmount the constraints of conventional chargers. Technological challenges and trends of EV energizing systems are evaluated in terms of battery performance, charging and discharging capabilities, grid integration and smart charging. The standards have been entrenched to ensure universal acceptance, communication between green energy vehicle and energizing station, grid communication, power quality and component safety. Various standards are set by the organizations IEC, ISO, IEEE and SAE for safety requirements, charging communications, battery recycling and test procedures. Finally future roadmap and challenges in implementation of EVs are presented with a focus of reducing greenhouse gases with a target of net zero pledges for each country.

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References

[1] A. Jenn, K. Laberteaux, R. Clewlow, New mobility service users' perceptions on electric vehicle adoption, Int. J. Sustain. Transp. 12 (7) (2018) 526–540.

[2] K.K. Bhatia, W.T. Riddell, Identifying and modeling key trade-offs between hydrogen fuel cell and electric vehicles, Int. J. Sustain. Eng. 9 (3) (2016) 215–222.

[3] L. Li, Z. Wang, F. Gao, S. Wang, J. Deng, A family of compensation topologies for capacitive power transfer converters for wireless electric vehicle charger, Appl. Energy 260 (2020), 114156.

[4] B. Maclnnis and J. A. Krosnick. (Oct. 2020). Climate insights 2020: Electric vehicles. Resources for the Future (RFF). [Online]. Available: https://www.rff.org/publications/reports/climateinsights2020-electric-vehicles

[5] United States Environmental Protection Agency. (Apr. 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks. [Online]. Available: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gasemissions-and-sinks

[6] Fu, Y.; Jia, C.; Huang, Y.; Ren,W. Influence of electric vehicles on reliability of power system containing wind power. In Proceedings of the 2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific), Harbin, China, 7–10 August 2017; pp. 1–5.

[7] Bangalore, P.; Bertling, L. Extension of test system for distribution system reliability analysis with integration of Electric Vehicles in distribution system. In Proceedings of the 2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies, Manchester, UK, 5–7 December 2011; pp. 1–7.

[8] Ammous, M.; Khater, M.; AlMuhaini, M. Impact of vehicle-to-grid technology on the reliability of distribution systems. In Proceedings of the 2017 9th IEEE-GCC Conference and Exhibition (GCCCE), Manama, Bahrain, 8–11 May 2017; pp. 1–6.

[9] C. McKerracher et al., ``Electric vehicle outlook 2021," BloombergNEF, London, U.K., Tech. Rep., Aug. 2021. [Online]. Available: https://about. bnef.com/electric-vehicle-outlook/

[10] A. Konig, L. Nicoletti, D. Schroder, S. Wolff, A. Waclaw, and M. Lienkamp, ``An overview of parameter and cost for battery electric vehicles," World Electr. Vehicle J., vol. 12, no. 21, pp. 129, Feb. 2021.

[11] M. Adhikari, L. P. Ghimire, Y. Kim, P. Aryal, and S. B. Khadka, ``Identication and analysis of barriers against electric vehicle use," Sustainability, vol. 12, pp. 120, Jun. 2020.

[12] G. Krishna, ``Understanding and identifying barriers to electric vehicle adoption through thematic analysis," Transp. Res. Interdiscipl. Perspect., vol. 10, pp. 19, Apr. 2021.

[13] Chang-Yeol Oh, Dong-Gyun Woo, Yun-Sung Kim, "A High-Efficient Nonisolated Single-Stage On-Board Battery Charger for Electric Vehicles", IEEE Transactions on Power Electronics, Vol. 28, No. 12, December 2013.

[14] M. Safayatullah, M. T. Elrais, S. Ghosh, R. Rezaii, and I. Batarseh,''A comprehensive review of power converter topologies and control methods for electric vehicle fast charging applications,'' IEEE Access, vol. 10, pp. 40753–40793, 2022, doi: 10.1109/ACCESS.2022.3166935.

[15] Electric Vehicle Inductive Coupling Recommended Practice, Standard SAE 5-1773, Feb. 1995.

[16] M. Shahjalal, T. Shams, M. N. Tasnim, M. R. Ahmed, M. Ahsan, and J. Haider, ''A critical review on charging technologies of electric vehicles,'' Energies, vol. 15, no. 21, p. 8239, Nov. 2022, doi:10.3390/en15218239.

[17] PNW. (2020). Charging Your Electric Vehicle. [Online]. Available: https://www.pnm.com/ev-charging

[18] M. Yilmaz and P. T. Krein, ‘‘Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles,’’ IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2151–2169,May 2013.
[19] SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler, Standard J1772, SAE, 2017.
[20] IEC. (2021). Plugs, Socket-Outlets, Vehicle Connectors and Vehicle Inlets—Conductive Charging of Electric Vehicles. [Online]. Available: https://webstore.iec.ch/publication/6582
[21] S. Bae and A. Kwasinski, ‘‘Spatial and temporal model of electric vehicle charging demand,’’ IEEE Trans. Smart Grid, vol. 3, no. 1, pp. 394–403, Mar. 2012.
[22] H. Tu, H. Feng, S. Srdic, and S. Lukic, ‘‘Extreme fast charging of electric vehicles: A technology overview,’’ IEEE Trans. Transport. Electrific., vol. 5, no. 4, pp. 861–878, Dec. 2019.
[23] D. Patil and V. Agarwal, ‘‘Compact onboard single-phase EV battery charger with novel low-frequency ripple compensator and optimum filter design,’’ IEEE Trans. Veh. Technol., vol. 65, no. 4, pp. 1948–1956, Apr. 2016, doi: 10.1109/TVT.2015.2424927.
[24] A. Khaligh and M. D'Antonio, ‘‘Global trends in high-power on-board chargers for electric vehicles,’’ IEEE Trans. Veh. Technol., vol. 68, no. 4, pp. 3306–3324, Apr. 2019, doi: 10.1109/TVT.2019.2897050.
[25] K. Fahem, D. E. Chariag, and L. Sbita, ‘‘On-board bidirectional battery chargers topologies for plug-in hybrid electric vehicles,’’ in Proc. Int. Conf. Green Energy Convers. Syst. (GECS), Mar. 2017, pp. 23–27.
[26] H. Karneddi, D. Ronanki, and R. L. Fuentes, ‘‘Technological overview of onboard chargers for electrified automotive transportation,’’ in Proc. 47th Annu. Conf. IEEE Ind. Electron. Soc. (IECON), Oct. 2021, pp. 1–6, doi: 10.1109/IECON48115.2021.9589679.
[27] G. Motors. (2022). Our Path to an All—Electric Future Zero Crashes, Zero Emissions, Zero Congestion. [Online]. Available: https: //www.gm.com/electric-vehicles#product
[28] Tesla. (2023). Onboard Charger. [Online]. Available: https://www.tesla.com/support/home-charging installation/onboard-charger
[29] Tesla. (2019). Introducing V3 Supercharging. [Online]. Available:https://www.tesla.com/blog/introducing-v3-supercharging
[30] J. Lee. (2018). Bidirectional Powering on-Board Charger, Vehicle Power Supply System Including the Same, and Control Method Thereof. [Online]. Available: https://patentimages.storage. googleapis.com/6a/9e/56/4a20a2df3d5fb0/US10046656.pdf
[31] R. Pandey and B. Singh, ‘‘A power factor corrected resonant EV charger using reduced sensor based bridgeless boost PFC converter,’’ IEEE Trans. Ind. Appl., vol. 57, no. 6, pp. 6465–6474, Nov. 2021, doi:10.1109/TIA.2021.3106616.
[32] H. Bai, M. McAmmond, J. Lu, Q. Tian, H. Teng, and A. Brown, ‘‘Design and optimization of a 98%-efficiency on-board level-2 battery charger using E-mode GaN HEMTs for electric vehicles,’’ SAE Int. J. Alternative Powertrains, vol. 5, no. 1, pp. 205–213, Apr. 2016, doi: 10.4271/2016-01-1219.
[33] SSG Acharige, ME Haque, MT Arif, N Hosseinzadeh, KN Hasan, AMT Oo, "Review of electric vehicle charging technologies, standards, architectures, and converter configurations", IEEE Access, vol. 11, pp. 41218–41255, 2023, doi: 10.1109/ACCESS.2023.3267164.
[34] X. Lu, K. L. V. Iyer, K. Mukherjee, and N. C. Kar, ‘‘Investigation of integrated charging and discharging incorporating interior permanent magnet machine with damper bars for electric vehicles,’’ IEEE Trans. Energy Convers., vol. 31, no. 1, pp. 260–269, Mar. 2016, doi: 10.1109/TEC.2015.2467970.
[35] K. T. Chau, C. C. Chan, and C. Liu, ‘‘Overview of permanent-magnet brushless drives for electric and hybrid electric vehicles,’’ IEEE Trans. Ind. Electron., vol. 55, no. 6, pp. 2246–2257, Jun. 2008.
[36] M. Y. Metwly, M. S. Abdel-Majeed, A. S. Abdel-Khalik, R. A. Hamdy, M. S. Hamad, and S. Ahmed, ‘‘A review of integrated on-board EV battery chargers: Advanced topologies, recent developments and optimal selection of FSCW slot/pole combination,’’ IEEE Access, vol. 8, pp. 85216–85242, 2020, doi: 10.1109/ACCESS.2020.2992741.
[37] A. K. Singh and M. K. Pathak, ‘‘A comprehensive review of integrated charger for on-board battery charging applications of electric vehicles,’’ in Proc. IEEE 8th Power India Int. Conf. (PIICON), Dec. 2018, pp. 1–6, doi: 10.1109/POWERI.2018.8704399.
[38] A. Clark, ‘‘Charging the future: Challenges and opportunities for electric vehicle adoption,’’ Harvard Kennedy School, Cambridge, MA, USA, HKS Work. Rep. RWP18-026, 2018.

[39] J. Lu, ‘‘A modular-designed three-phase high-efficiency high-power density EV battery charger using dual/triple-phase-shift control,’’ IEEE Trans. Power Electron., vol. 33, no. 9, pp. 8091–8100, Sep. 2018, doi:10.1109/TPEL.2017.2769661.

[40] C. Shi, Y. Tang, and A. Khaligh, ‘‘A three-phase integrated onboard charger for plug-in electric vehicles,’’ IEEE Trans. Power Electron., vol. 33, no. 6, pp. 4716–4725, Jun. 2018, doi:10.1109/TPEL.2017.2727398.

[41] T. Na, X. Yuan, J. Tang, and Q. Z. Hang, ‘‘A review of on-board integrated electric vehicles charger and a new single-phase integrated charger,’’ CPSS Trans. Power Electron. Appl., vol. 4, no. 4, pp. 288–298, Dec. 2019, doi: 10.24295/CPSSTPEA.2019.00027.

[42] I. Subotic, N. Bodo, E. Levi, B. Dumnic, D. Milicevic, and V. Katic, ‘‘Overview of fast on-board integrated battery chargers for electric vehicles based on multiphase machines and power electronics,’’ IET Electr. Power Appl., vol. 10, no. 3, pp. 217–229, 2016, doi: 10.1049/ietepa. 2015.0292.

[43] A. Khaligh and M. D’Antonio, ‘‘Global trends in high-power on-board chargers for electric vehicles,’’ IEEE Trans. Veh. Technol., vol. 68, no. 4, pp. 3306–3324, Apr. 2019, doi: 10.1109/TVT.2019.2897050.

[44] Continental. (2023). Mobility Fair EVS30: Continental Presents Innovative Charging Technologies for All Applications. [Online]. Available: https://www.continental.com/en/press/press-releases/2017-10-09-charging-solutions/

[45] F Zhu, L Li, Y Li, K Li, L Lu, X Han, J Du, M Ouyang, “Does the battery swapping energy supply mode have better economic potential for electric heavy-duty trucks?”, eTransportation, Vol. 15, 100215, January 2023, https://doi.org/10.1016/j.etran.2022.100215

[46] Furkan Ahmad, Mohammad Saad Alam, Ibrahim Saad Alsaidan, Samir M. Shariff, “Battery swapping station for electric vehicles: opportunities and challenges”, IET Smart Grid, 2020, Vol. 3 Iss. 3, pp. 280-286, https://doi.org/10.1049/iet-stg.2019.0059

[47] Wang, X., Yuen, C., Hassan, N.U., et al.: ‘Electric vehicle charging station placement for urban public bus systems’, IEEE Trans. Intell. Transp. Syst., 2017, 18, (1), pp. 128–139

[48] Asaad, M., Ahmad, F., Alam, M.S., et al.: ‘Iot enabled monitoring of an optimized electric vehicle's battery system’, Mob. Netw. Appl., 2017, 23, (4), pp. 994–1005

[49] Ahmad, F., Alam, M.S., Shahidehpour, M.: ‘Optimal placement of electric, hybrid and plug-in hybrid electric vehicles (xEVs) in Indian power market’. 2017 Saudi Arabia Smart Grid Conf. (SASG 2017), Jeddah, Kingdom of Saudi Arabia, 2018, pp. 1–7

[50] Hua, J.: ‘Progress in battery swapping technology and demonstration in China’, Tsinghua University, 2016

[51] Shariff, S.M., Alam, M.S., Ahmad, F., et al.: ‘System design and realization of a solar-powered electric vehicle charging station’, IEEE Syst. J., 2019, PP, pp. 1–12

[52] ‘Challenges for battery swapping station’, 2017. Available at https://getsetojo.com/blogs/blog/challenges-for-battery-swapping-over-chargingstations-for-evs-in-india, Accessed 10 January 2019

[53] Mahoor, M., Hosseini, Z.S., Khodaei, A.: ‘Electric vehicle battery swapping station’. CIGRE Grid of the Future Symp., Paris, France, 2017, pp. 1–5

[54] Yang, S., Wu, M., Jiang, J., et al.: ‘Optimal strategy for economic operation of electric bus battery swapping station’, Dianwang Jishu/Power Syst. Technol., 2014, 38, (2), pp. 335–340

[55] Gao, Z., Lin, Z., LaClair, T.J., et al.: ‘Battery capacity and recharging needs for electric buses in city transit service’, Energy, 2017, 122, pp. 588–600

[56] Sarker, M.R., Dvorkin, Y., Ortega-Vazquez, M.A.: ‘Optimal participation of an electric vehicle aggregator in day-ahead energy and reserve markets’, IEEE Trans. Power Syst., 2016, 31, (5), pp. 3506–3515

[57] Sarker, M.R., Dvorkin, Y., Ortega-Vazquez, M.A.: ‘Optimal participation of an electric vehicle aggregator in day-ahead energy and reserve markets’, IEEE Trans. Power Syst., 2016, 31, (5), pp. 3506–3515

[58] Cheah, L., Heywood, J.: ‘The cost of vehicle electrification: a literature review’. MIT Energy Initiative Symp., Cambridge, MA, USA., 2010, pp. 2–6

[59] F Zhu, L Li, Y Li, K Li, L Lu, X Han, J Du, M Ouyang, “Does the battery swapping energy supply mode have better economic potential for electric heavy-duty trucks?”, eTransportation Vol. 15, January 2023, 100215, https://doi.org/10.1016/j.etran.2022.100215

[60] G Palani, U Sengamalai, P Vishnuram, B Nastasi, “Challenges and Barriers of Wireless Charging Technologies for Electric Vehicles”, Energies 2023, 16, 2138. https://doi.org/10.3390/en16052138

[61] Muhammad Amjad, Muhammad Farooq-i-Azam, Qiang Ni, Mianxiong Dong, Ejaz Ahmad Ansari, “Wireless charging systems for electric vehicles”, Renewable and Sustainable Energy Reviews, Vol. 167, October 2022, 112730, https://doi.org/10.1016/j.rser.2022.112730
[62] Qiu, C.; Chau, K.T.; Liu, C.; Chan, C.C. Overview of wireless power transfer for electric vehicle charging. Electr. Veh. Symp. Exhib.2013, 7, 1–9.
[63] Chabalko, M.J.; Besnoff, J.; Ricketts, D.S. Magnetic Field Enhancement in Wireless Power with Metamaterials and Magnetic Resonant Couplers. IEEE Antennas Wirel. Propag. Lett. 2016, 15, 452–455.
[64] Agbinya, J.I. Wireless Power Transfer; River Publishers: Aalborg, Denmark, 2012; Chapter 4; p. 119
[65] Dashora, H.K.; Bertoluzzo, M.; Buja, G. Reflexive properties for different pick-up circuit topologies in a distributed IPT track. In Proceedings of the 2015 IEEE International Conference on Industrial Informatics, INDIN 2015, Cambridge, UK, 22–24 July 2015; pp. 69–75.
[66] Kazmierkowski, M.P.; Moradewicz, A.J. Unplugged but connected: Review of contactless energy transfer systems. IEEE Ind. Electron. Mag. 2012, 6, 47–55.
[67] Maxwell, J.C. Summary for Policymakers. Treatise Electr. Magn. 1954, 53, 1–30.
[68] Lopez-Ramos, A.; Menendez, J.R.; Pique, C. Conditions for the Validity of Faraday’s Law of Induction and Their Experimental Confirmation. Eur. J. Phys. 2008, 29, 1069–1076.
[69] Maxwell, J. A Dynamical Theory of the Electromagnetic Field. Proc. R. Soc. 1863, 459–512.
[70] Lu, X.; Wang, P.; Niyato, D.; Kim, D.I.; Han, Z. Wireless Charging Technologies: Fundamentals, Standards, and Network Applications. IEEE Commun. Surv. Tutor. 2016, 18, 1413–1452.
[71] Leblanc, M.; Hutin, M. Transformer System for Electric Railways. U.S. Patent 527,857, 1894.
[72] Wireless Transmission of Energy. Available online: https://teslaresearch.jimdo.com/wireless-transmission-of-energy-1/
[73] JBolger, G.; Kirsten, F.A.; Ng, L.S. Inductive power coupling for an electric highway system. In Proceedings of the 28th IEEE Vehicular Technology Conference, Denver, CO, USA, 22–24 March 1978; pp. 137–144.
[74] Zell, C.E.; Bolger, J.G. Development of an engineering prototype of a roadway powered electric transit vehicle system: A public/private sector program. In Proceedings of the 32nd IEEE Vehicular Technology Conference, San Diego, CA, USA, 23–26 March 1982; Volume 32, pp. 35–38.
[75] California PATH Program Roadway Powered Electric Vehicle Project Track Construction And Testing Program Phase 3D. Traffic, 1994. Available online: https://escholarship.org/uc/item/1jr98590Accessed (accessed on 20 December 2022).
[76] Matsumoto, H. Research on solar power satellites and microwave power transmission in Japan. IEEE Microw. Mag. 2002, 3, 36–45.
[77] Shinohara, N.; Kubo, Y.Wireless Charging for Electric Vehicle with Microwaves. In Proceedings of the 2013 3rd International Electric Drives Production Conference (EDPC), Nuremberg, Germany, 29–30 October 2013.
[78] Brown,W.C. The History of Power Transmission by RadioWaves. IEEE Trans. Microw. Theory Tech. 1984, 32, 1230–1242.
[79] Range, S. Beam Efficiency of Wireless Power Transmission via Radio Waves from Short Range to Long Range. J. Electromagn. Eng. Sci. 2010, 10, 4–10.
[80] Kapranov, V.V.; Matsak, I.S.; Tugaenko, V.Y.; Blank, A.V.; Suhareva, N.A. Atmospheric turbulence effects on the performance of the laser wireless power transfer system. In Free-Space Laser Communication and Atmospheric Propagation XXIX; SPIE: San Francisco, CA, USA, 2017; p. 100961E.
[81] Dickinson, R.M.M. Performance of a High-Power, 2.388-GHz Receiving Array in Wireless Power Transmission Over 1.54 km. In MTT-S International Microwave Symposium Digest; IEEE: Piscataway, NJ, USA, 1976; Volume 76, pp. 139–141.
[82] Shinohara, N.Wireless charging system of electric vehicle with GaNSchottky diodes. In Proceedings of the IMS2011Workshop WFA “Wireless Power Transmission”, Baltimore, MD, USA, 10 June 2011; p. CD-ROM.
[83] Tritschler, J.; Reichert, S.; Goeldi, B. A practical investigation of a high power, bidirectional charging system for electric vehicles. In Proceedings of the 16th European Conference on Power Electronics and Applications, Lappeenranta, Finland, 26–28 August 2014; pp. 1–7.
[84] Triviño, A.; González-González, J.M.; Aguado, J.A. Wireless Power Transfer Technologies Applied to Electric Vehicles: A Review. Energies 2021, 14, 1547.

[85] Wireless Electric Vehicle Charging Technology|Halo & Power Transfer|Qualcomm. Available online: https://www.qualcomm. com/solutions/automotive/wevc (accessed on 15 June 2019).
[86] R. Schuylenbergh, Koeranadvan; Puers, Inductive Powering: Basic Theory and Application to Biomedical System, no. 1. 2014.Available online: https://link.springer.com/book/10.1007/978-90-481-2412-1 (accessed on 19 February 2023).
[87] Kamineni, A.; Covic, G.A.; Boys, J.T. Analysis of Coplanar Intermediate Coil Structures in Inductive Power Transfer Systems. IEEE Trans. Power Electron. 2015, 30, 6141–6154.
[88] Rajendran G, Vaithilingam CA, Misron N, Naidu K, Ahmed MR. A comprehensive review on system architecture and international standards for electric vehicle charging stations. Journal of Energy Storage. 2021 Oct 1;42:103099., https://doi.org/10.1016/j.est.2021.103099
[89] IEC Standards: Plugs, socket-outlets, vehicle connectors and vehicle inlets - conductive charging of electric vehicles -part 3: dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers. Available: https://webstore.iec.ch/publication/6584 (accessed August 16, 2023).
[90] IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces," in IEEE Std 1547- 2018 (Revision of IEEE Std 1547-2003), pp.1-138, 6 April 2018, doi:10.1109/I EEESTD.2018.8332112.
[91] Electric vehicle charging stations - standards. Available: https://www.iso.org/standards.html (accessed August 16, 2023).
[92] CHAdeMO protocol development. 2018. Available: https://www.chademo.com/activities/protocol-development/ (accessed August 16, 2023).
[93] N. F. P. Association, NFPA 70: National Electrical Code, NationalFireProtectionAssoc, 2011.
[94] U. Laboratories.Electric vehicle infrastrucure services - UL. Available: https://www.ul.com/services/electric-vehicle-ev-infrastructure-services (accessed August 16, 2023).
[95] Society of automation engineering - interantional standards on EV charging stations. Available: https://www.sae.org/ (accessed August 16, 2023).
[96] H. Hirsch, S. Jeschke, L. Wei, M. Trautmann, J. Barenfanger, M. Maarleveld, J. Heyen, and A. Darrat, ''Latest development of the national and international EMC-standards for electric vehicles and their charging infrastructure,'' in Proc. IEEE Int. Symp. Electromagn. Compat. (EMC), Aug. 2015, pp. 708–713, doi: 10.1109/ISEMC.2015.7256250.
[97] G. Rajendran, C. A. Vaithilingam, N. Misron, K. Naidu, and M. R. Ahmed, ''A comprehensive review on system architecture and international standards for electric vehicle charging stations,'' J. Energy Storage, vol. 42, Oct. 2021, Art. no. 103099, doi: 10.1016/j.est.2021.103099.
[98] IRENA. (2019). A New World—The Geopolitics of the Energy Transformation. [Online]. Available: https://www.irena.org//media/Files/IRENA/Agency/Publication/2019/Jan/Global_commission_geopolitics_new_world_2019.pdf
[99] D. Kettles and R. Raustad. (2017). Electric Vehicle Charging Technologies Analysis and Standards: Final Research Project Report. [Online]. Available: https://rosap.ntl.bts.gov/view/dot/32266
[100] IEEE Electric Vehicle Charging Conformity Assessment Program, Available online: https://standards.ieee.org/products-programs/icap/programs/ev/ (accessed August 18, 2023)
[101] J. Francfort. (2010). Electric Vehicle Charging Levels and Requirements Overview. Idaho National Laboratory. [Online]. Available:https://avt.inl.gov/sites/default/files/pdf/presentations/CleanCitiesWedinarCharging12-15-10.pdf
[102] M. Gjelaj, C. Traholt, S. Hashemi, and P. B. Andersen, ''Cost-benefit analysis of a novel DC fast-charging station with a local battery storage for EVs,'' in Proc. 52nd Int. Universities Power Eng. Conf. (UPEC), Aug. 2017, pp. 1–6, doi: 10.1109/UPEC.2017.8231973.
[103] Distributed Energy Integration Program—Electric Vehicles Grid Integration, AEMO, Melbourne, VIC, Australia, 2021.
[104] R. Frost. Power of ISO Standards for Electric Vehicles. [Online]. Available: https://www.iso.org/news/2013/03/Ref1715.html
[105] Regulations and Standards for Clean Trucks and Buses: On the Right Track? OECD Publishing, Paris, France, 2020. Accessed: Aug. 22, 2023. [Online]. Available: https://www.itf-oecd.org/sites/default/files/docs/regulations-standards-clean-trucks-buses_0.pdf

[106] R. Collin, Y. Miao, A. Yokochi, P. Enjeti, and A. von Jouanne, ‘‘Advanced electric vehicle fast-charging technologies,’’ Energies, vol. 12, no. 10, p. 1839, May 2019.

[107] USDRIVE. (2017). Electrical and Electronics Technical Team Roadmap. U.S. Department of Energy. [Online]. Available: https://pdf4pro.com/amp/view/electrical-and-electronics-technicalteam-roadmap-5f392a.html

[108] Virta. (2021). Vehicle-to-Grid (V2G): Everything You Need to Know.[Online]. Available: https://www.virta.global/vehicle-to-grid-v2g

[109] M. S. H. Lipu, M. A. Hannan, T. F. Karim, A. Hussain, M. H. M. Saad, A. Ayob, M. S. Miah, and T. M. I. Mahlia, ‘‘Intelligent algorithms and control strategies for battery management system in electric vehicles: Progress, challenges and future outlook,’’ J. Cleaner Prod., vol. 292, Apr. 2021, Art. no. 126044, doi: 10.1016/j.jclepro.2021.126044.

[110] R. Bass, R. Harley, F. Lambert, V. Rajasekaran, and J. Pierce, ‘‘Residential harmonic loads and EV charging,’’ in Proc. IEEE Power Eng. Soc. Winter Meeting. Conf., vol. 2, Aug. 2010, pp. 803–808, doi:10.1109/PESW.2001.916965.

[111] (2022). Internet of Vehicles (IoV): Revolutionizing Transportation of Tomorrow Riding on 5G and Edge AI. [Online]. Available: https://www.wipro.com/infrastructure/

[112] J.Wang, K. Zhu, and E. Hossain, ‘‘Green Internet of Vehicles (IoV) in the 6G era: Toward sustainable vehicular communications and networking,’’ IEEE Trans. Green Commun. Netw., vol. 6, no. 1, pp. 391–423, Mar. 2022, doi: 10.1109/TGCN.2021.3127923.

[113] S. Pareek, A. Sujil, S. Ratra, and R. Kumar, ‘‘Electric vehicle charging station challenges and opportunities: A future perspective,’’ in Proc. Int. Conf. Emerg. Trends Commun., Control Comput., Feb. 2020, pp. 1–6, doi: 10.1109/ICONC345789.2020.9117473.

[114] Jabbari, M.M., Tohidi, H., (2012). “Important factors in determination of innovation type”. Procedia Technology, 1, 570-573. https:// doi: 10.1016/j.protcy.2012.02.124.

[115] Jabbari, M.M., Tohidi, H., (2012). “Providing a Framework for Measuring Innovation within Companies”. Procedia Technology, 1, 583-585. https:// doi: 10.1016/j.protcy.2012.02.127

[116] "International energy agency - global EV outlook 2021," Available: https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf (accessed May 25, 2021).

[117] F. Manríquez, E. Sauma, J. Aguado, S. de la Torre, and J. Contreras, ‘‘The impact of electric vehicle charging schemes in power system expansion planning,’’ Appl. Energy, vol. 262, Mar. 2020, Art. no. 114527, doi: 10.1016/j.apenergy.2020.114527.

[118] A. S. Al-Ogaili, ‘‘Review on scheduling, clustering, and forecasting strategies for controlling electric vehicle charging: Challenges and recommendations,’’ IEEE Access, vol. 7, pp. 128353–128371, 2019, doi:10.1109/ACCESS.2019.2939595.

[119] M. Stecca, L. R. Elizondo, T. B. Soeiro, P. Bauer and P. Palensky, ‘‘A comprehensive review of the integration of battery energy storage systems into distribution networks,’’ IEEE Open J. Ind. Electron. Soc., vol. 1, pp. 46–65, 2020. Accessed: Feb. 14, 2023, doi:10.1109/OJIES.2020.2981832.