A Comprehensive Review on Solar Powered Electric Vehicle Charging System

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ABSTRACT
Electric vehicles (EVs) are becoming increasingly popular in many countries of the world. EVs are proving more energy efficient and environmental friendly than ICEVs. But the lack of charging stations restricts the wide adoption of EVs in the world. As EV usage grows, more public spaces are installing EV charging stations. On the other hand, if EVs are charged via existing utility grid powered by fossil fuel-based generation system, then it affects the distribution system and could not be environmentally friendly. As solar has great potential to generate the electricity from PV panel, the charging of EVs from PV panels would be a great solution and also a sustainable step toward the environment. This paper presents a comprehensive analysis of solar PV-EV charging systems and deployment in the world. Analytical methods were proposed to obtain information about EV charging behavior, modes of charging station operation, and geolocation of charging station users. The methodology presented here was time- and cost-effective, and very helpful to the researchers and students in this field.

1. Introduction
1.1. Background
Air pollution, particularly PM, is a serious challenge facing by transportation sector of various countries. The World Health Organization (WHO) reported 3.7 million death tragedies in the world below 60 in 2012 due to atmospheric air pollution, 90% population are located in developing countries [1]. Presently 1.7 million child expiries a year and total 9 million people died each year, says WHO [2,3]. And nearly18% of premature births (before 37 weeks gestation) (globally) are related to exposure to outdoor air pollution [3]. China reported 1.22 and 1.28 million premature death cases in 2005 and 2010, respectively [4]. According to an estimate of the 2017 Global Burden of Disease, atmospheric air pollution is responsible for more than 4.2 million early deaths, of these, India accounts for 1.1 million each year expiries [5]. Although due to smaller vehicle fleet relative to large population, India fixes low per capita transportation emissions. The big factor is the exponential growth of vehicle fleet, because of the...
growth in vehicle sales (about 10 million in 2007 to over 21 million in 2016 and expected to nearly double to about 200 million by 2030 in India [6]. A number of health and medical organizations claimed that the diesel engine exhaust is more prone to cancer in humans [7]. Also, rising fuel costs and growing public concerns on environmental problems such as air quality, global warming, etc. have led the governments and automobile industries to develop eco-friendly, emission-free means of transportation [8] i.e. green transportation systems e.g. walking, cycling, regular public conveyance, and rail transport system, etc. Vehicles include natural gas vehicle, hybrid energy vehicle, electric vehicle, hydrogen-powered vehicle, and solar energy vehicle [9].

Vehicle emission standards are adopted to incorporate soot free fleet services around the world [10,11]. Countries like Europe, the United States, Japan, and India adopt Euro 6/VI equivalent standards (for light and heavy-duty vehicles) that reduce 99% emissions like (NOx), (NH3), (N2O), etc. [12,6] and justifying the regulation of risk of ischemic heart disease, lung cancer, stroke, and asthma [13]. But the best option is renewable energy.

The outcome of this paradigm shift, EVs and PHEVs are emerging as attractive alternatives to ICEVs [14]. Owing to the importance of EVs, the national and international governments worldwide (U.S.A., U.K., China, Germany, France, Japan, Norway, Netherlands, etc.) have passed various resolutions and supervisory steps and allocated substantial fund to encourage EV and PEV deployment and implementation [15]. Long-term planning scenarios specify that the EVs must capture almost entire global vehicle fleet, mostly propelled by renewable sources, by 2050 to avoid worst-case global climate change scenarios [16].

The advantages of EV-PV charging system are. (1) Reduction in the EV charging load penetration on the grid. (2) The voltage problem in the distribution system is avoided [17]. (3) Electric supply charges paid to the grid. (4) Efficiency is on the higher side in direct DC EV-PV interconnection. (5) Energy storage reduces as EV battery doubles up the PV storage. (6) Feasibility of Vehicle-to-grid (V2G) and Vehicle-to-home (V2H) strategies [18–22]. (7) Lower fuel cost and no emissions at the tailpipe (‘well to wheel’) [23]. (8) No maintenance/noise because of no moving part. (9) Installation is feasible everywhere [24].

The development and widespread adoption of EVs and PHEVs are dependent upon the development of battery technology [25] and facility for these vehicles, in order to meet their power requirements [26]. So complete charging infrastructure with sophisticated equipment is indispensable for promoting EVs.

### 1.2. Significant Contributions

The outlined contributions of this review paper are as follows:

- The aim of the subject matter is to study comprehensively several aspects and methodologies for solar PV-EV charging technologies.
- The paper presents charging standards including techniques and modes of solar charging, economic analysis, roadblocks and challenges, and sustainability, etc.
- Control and safety techniques with respect to PVCS, and also the working of the commercialized business model is explained.
- To assess the feasibility, a detailed insight of different proposed solar PV charging technologies are discussed.

The manuscript is elaborated into six sections followed by an introduction and ended up with the conclusion. In the second section, mathematical modeling and global solar PV utilization are presented. In the third section, a survey of the existing electric vehicle charging stations globally with their charging levels and standards are presented. Also, control and safety, and business model, etc. developed so far are analyzed. The fourth section comprises different solar charging technologies with their topologies. In the fifth section, the last section, a technical insight from the issue of environmental and economic perspective is investigated.

### 2. Solar PV Power Generation Potential in the World

Solar potential received by the planet earth in 1 h from the sun can fulfill all energy needs for one year [27] and it is the sustainable and cleanest form of energy that earth received [22]. It can be concluded that the estimated SPV based energy generation is probably to reach its maximum potential in another 40 years [24]. The measurement of incident sunlight on any surface (i.e. insolation) can be done as energy per unit time per unit area (irradiance) or power per unit area [28]. Roughly, the earth receives four million exajoules (1 EJ = 1018 J) of solar energy annually, out of which 5 × 104 EJ is claimed to be practically harvestable [29].

#### 2.1. Modeling Framework of EV Integrated PVCS

Being nonlinear device, a solar cell can be represented as a current source model (Figure 1) [30–32].

The governing equation by KCL for current ($I_{PV}$):

$$I_{PV} = I_L - (I_D + I_{sh})$$  \hspace{1cm} (1)
Here, $I_L$ = light generated current in the cell (Ampere), $I_p$ = voltage-dependent current lost in recombination (drop in diode) and $I_s$ = shunt resistance drop.

In above single diode circuit model, $I_D$ is calculated by the ideal diode Shockley equation:
\[
I_D = I_o \left[ e^{\frac{V_{PV}+V_{j}+kT}{nV_T}} - 1 \right]
\]  
(2)

Where $V_{PV}$ is module voltage output, $I_{PV}$ is module current output, $n$ is the diode ideality factor (for a single junction diode it is usually between 1 and 2), $I_o$ is the saturation current, and $V_T$ is the thermal voltage given by:
\[
V_T = \frac{kT}{q}
\]
(3)

Where $k$ is Boltzmann’s constant ($1.381 \times 10^{-23}$ J/K) and $q$ is the elementary charge ($1.602 \times 10^{-19}$ C) and $T$ is the module temperature (K).

Writing the shunt current equation as:
\[
I_{sh} = \left( \frac{V_{PV} + I_{PV}R_s}{R_{sh}} \right)
\]
(4)

Where $R_s$ and $R_{sh}$ are the series and shunt resistances, respectively (Ω).

Where $R_{sh} >> R_s$

The typical governing equation of I-V characteristics of a PV array for the single diode model is:
\[
I_{PV} = I_L - I_o \left[ e^{\frac{V_{PV}+V_{j}+kT}{nV_T}} - 1 \right] - \left( \frac{V_{PV} + I_{PV}R_s}{R_{sh}} \right)
\]
(5)

And also the power is given by:
\[
P_{PV} = V_{PV} \times I_{PV}
\]
(6)

For efficient working of solar panels, the ambient temperature must be low [33]. The solar PV power conversion efficiency ($\eta_{solar}$) varies marginally with temperature e.g. the decrement rate of $\eta_{solar}$ is 0.2–0.5% for the temperature rise of 1 °C. Generally, to check larger variations in temperature, solar cell makers typically use heat insulation technique. Consequently, the change in $\eta_{solar}$ is rather small due to temperature fluctuations [34]. This clarifies the reason behind the researchers that assume solar cell efficiency as constant. Besides $\eta_{solar}$, the electrical power output at particular solar irradiation ($P_{solar}$) is likewise calculated by:
\[
P_{solar}(s) = \eta_{solar} \times sa \text{ (Watts)}
\]
(7)

i.e. the solar irradiation intensity ($s$ in W/m²) is multiplied by the combined area of solar cells ($a$ in m²).

A frequently used solar energy universal model [35] is:
\[
\frac{E_T}{E_{extra}} = a + b \frac{S}{S_o}
\]
(8)

It is a linear model where $E_T$ is the total/global solar energy, $E_{extra}$ means the extraterrestrial solar energy, $S$ denotes the day length, while $S_o$ determines the total number of sunshine hours, and $a$ & $b$ are the constants of the model.

Relying on above-listed equations/formulas, here is a comparative analysis of numerous scientific studies conducted so far on the costs of carbon life cycle for solar (both PV and thin film). The main gist is the average 3-year payback, means after 3 years, as much energy solar panels create as was demanded in their initial manufacturing and installation processes. And in the leftover 22–27 years of their useful life, solar panels would be ‘carbon negative.’

Now this payback period might vary considerably subject to your location. A typical estimate for ‘peak sun hours’ (Table 1) [36,37] in any country (a numerically equivalent data for the aggregated amount of time for which sun averages 1 kWh/m² intensity) is calculated here. Say, there is a standard 300-watt solar panel fixed (no tracking) at an optimal location. The assumption is there is no shadow on the panel during peak sun hours. The panel is rated to produce 300 watts within 1 h of highest solar intensity. If the typical generation potential is 7 × 300 watts = 2.1 kWh per day with that selected one panel. You have to shave off about 10% for efficiency (inverter and wiring) losses, so net generation is 1.89 kWh/panel/day production or 690 kWh per year.

If for instance, the peak sunshine is available almost for 4 h/day, so it would be expected to generate 1.2 kWh each day with the same panel, or 438 kWh/year. This average is varying place to place throughout the world. Suppose the national average of U.S. is somewhere about 4.5 h/day (local average is varying e.g. 10.8 h average for California, U.S.A. is found from Table 1), on an average, a 300-watt panel produces 1.35 kWh/day or 493 kWh/year. Now, for a typical lifespan of 25 years, the panel would yield about 12325 kWh. In Sweden, According to the study, a typical solar panel generates 50 g of CO₂ per kWh, hence a total of 616 kg of CO₂. Of course, we find a significant drop in efficiency characteristics of solar panels due to high temperature in hotter climates, and thus the amount of energy could be twice for the same 50 g of CO₂ making it...
potential map has been prepared based on solar irradiation maps in the earlier studies, the present work has been carried out with a focused attention directly on solar energy generation considering various parameters. Here it is shown that SPV power generation does not depend on solar radiation alone at a location. Instead, there are various other factors that influence the energy generation. Some of them are working conditions and location, ambient temperature, wind velocity and other parameters like weather and topographic conditions and environmental factors such as the geometric location of the sun, and irradiation levels [39,41,42], etc. The locations with high and low solar energy generation potential have been identified through systematic analysis by computing the solar energy parameters at every grid point (1° × 1°) in [43].

Figure 2 shows a typical solar irradiance map listing top ten countries with respect to their installed solar power in the world [42]. Solar energy potential database is provided by the Ministry of New and Renewable Energy (MNRE).

Table 1. Monthly average hours per day of sunshine by latitude and altitude, data from [37].

| Location | Beijing | Tokyo | Berlin | California | Rome | London | Delhi | Paris | Perth | Madrid |
|----------|---------|-------|--------|------------|------|--------|-------|-------|-------|--------|
| Longitude/Latitude | 39°N, 116°E | 35°N, 139°E | 52°N, 13°E | 36°N, 119°W | 41°N, 12°E | 51°N, 0.1278°E | 28°N, 77°E | 48°N, 2°E | 32°S, 115°E | 40°N, 3.7°E |
| Sea level | 44 m | 40 m | 34 m | 733 m | 139 m | 35 m | 227 m | 35 m | 31 m | 667 m |
| January | 6.26 | 5.9 | 1.5 | 7.5 | 3.9 | 1.8 | 6.9 | 2.1 | 10.4 | 4.77 |
| February | 6.5 | 5.8 | 2.6 | 8.5 | 4.75 | 2.4 | 7.7 | 2.8 | 9.8 | 5.6 |
| March | 7.47 | 5.2 | 3.9 | 10.4 | 5.38 | 4.1 | 7.7 | 4.9 | 8.8 | 6.9 |
| April | 8.4 | 5.86 | 5.3 | 11.7 | 6.7 | 6 | 8.7 | 7.4 | 7.5 | 7.7 |
| May | 9.14 | 5.4 | 7 | 13.16 | 8.5 | 5.9 | 8.5 | 7.1 | 5.7 | 8.77 |
| June | 8.71 | 4.2 | 7.4 | 14.1 | 9.5 | 5.8 | 6.5 | 7.6 | 4.8 | 10.3 |
| July | 6.85 | 4.7 | 7 | 15 | 10.7 | 6.3 | 5.3 | 8 | 5.4 | 11.5 |
| August | 7.33 | 5.6 | 6.8 | 14 | 9.6 | 5.3 | 5.7 | 6.8 | 6 | 10.8 |
| September | 7.48 | 4 | 5.2 | 11.26 | 7.9 | 4.7 | 7.3 | 5.6 | 7.2 | 8.7 |
| October | 7.4 | 4.2 | 3.6 | 10.46 | 6.3 | 3.3 | 8.68 | 4.5 | 8.1 | 6.4 |
| November | 6.2 | 4.9 | 1.7 | 8.36 | 4.3 | 2 | 8.23 | 2.3 | 9.6 | 5.2 |
| December | 5.8 | 5.7 | 1.19 | 6.8 | 3.6 | 1.6 | 6.96 | 1.6 | 10.4 | 4 |
| Annual | 7.3 | 5.2 | 4.45 | 10.8 | 6.8 | 4.1 | 7.4 | 5.1 | 7.8 | 7.58 |

Figure 2. Solar resource map [37]. Source: “Download free solar resource maps | Solargis.” [Online]. [Accessed 2017 Nov 14] Available from: http://solargis.com/products/maps-and-gis-data/free/download/world.
the equator is enormously high due to their convenient location as shown. Countries like India, Australia, etc. [44] being tropical, have rich solar resource e.g. India receives nearly 3000 h of sunshine every year, which is equivalent to 5000 trillion kWh of energy and can generate over 1900 billion units of solar power annually, which is enough to service the entire annual power demand even in 2030 [45].

Utility and power conversion industries are preparing for the grid integration challenges of increasing renewable sources, such as the effects of sudden, significant fluctuations in a PV system's output power. Prior work examined the negative effects of PV variability on localized power quality, which can include flicker, frequency instability in small grids, increased wear on conventional voltage regulator equipment and frequency limits. This problem is taken in the upcoming section of this manuscript. These effects present a major challenge to higher penetration of PV, particularly at the distribution level [46]. The fluctuations in the PV power have been removed with the use of battery [47] and/or ultracapacitors [48]. Also, solar energy is in dilute/distributed form and very intermittent in nature compared to coal/nuclear energy which is concentrated and have very high energy density. So harnessing solar energy imposes huge land requirement problem as well.

3. EV and PHEV Charging Systems

3.1. Globally Electric Vehicle Charging Infrastructure Deployment

In the U.S., an official national goal of deploying one million EVs on the road by 2015 has been established, and the government has implemented several policies to encourage public domain for achieving electrification at all levels [49]. The Ministry of Transportation, Ontario, Canada, as stated, the province is spending $20 million through its Green Investment Fund to build approximately 500 electric vehicle charging stations (EVCSs) at about 250 different locations in Ontario by 2017 [50]. The German National Electric Mobility Platform (NPE) envisages around 1,000,000 EVs in Germany by 2020 with a demand of about 70,000 public on-street charging spots specifically. To way out the problems faced by China's renewable energy exploitation practices and to cope with the growing energy demand by electric vehicles, a model for setting up a number of solar-powered charging stations for electric vehicles is designed in [51]. In May 2017, 10 countries (Canada, China, France, Germany, Japan, the Netherlands, Norway, Sweden, the U.K., and the U.S.) have come together and formed a multi-government policy forum i.e. Electric Vehicles Initiative (EVI), dedicated to accelerating the growth of electric vehicles worldwide. India and Korea are also engaged in the EVI's activities, while South Africa was an EVI member up to 2016 and continues as an active observer [52]. The Indian Government and automobile companies have joined hands for the mission of adopting e-vehicles and other alternate clean fuel to check the emissions from the transportation sector. Hence, the first document in 2013 on the EV mission was presented in the country as National Electric Mobility Mission Plan (NEMMP) 2020, which become an Act in 2015. And, the FAME (Faster Adoption and Manufacturing of (Hybrid & Electric Vehicles) India Scheme was also announced in 2015 to motivate the Electric Vehicle mission in India by subsidizing both the consumer and utility sides [53,54]. The biggest problem India now suffers is in terms of infrastructure, mainly unavailability of the charging station. We still don’t have a significant number of charging stations in the country. Collectively, the EVI members account for most of the global EV market and stock (95% of all electric car registrations and 95% of the total stock).

Figure 2 shows existing public charging infrastructure in the world [15]. From this data, the total no. of chargers are slow chargers = 212394 and fast chargers = 109871 [55].

3.2. Charging Systems and Their Standardization

3.2.1. Electric Vehicle Charging Standards

Plug-in hybrid electric vehicles (PHEVs) paves the way for partial electrification of the transportation sector [56] while full electric vehicles (EVs) offers complete electrification of the transportation sector.

Figure 3 shows different charging levels [57–61]. For plug-in electric vehicles (PEVs), on-board level-1 or level-2 chargers provide office daytime or home overnight charging, whereas high-power off-board chargers provide fast charging [62]. An on-board integrated charger [63], capable of fast charging for PEVs, can combine the advantages of both conventional on-board as well as off-board chargers [64]. Focusing on the design of the vehicle and type and capacity of the battery used, different charging levels have been standardized by different organizations in the world. Accordingly, charging time and behavior varies from vehicle to vehicle. So, the design of PV-EV charger must be according to above-mentioned requirements (Figure 4).

3.2.1.1. AC Charging System. AC charging system provides an AC supply that is converted into DC to charge the batteries. This system needs an AC-DC converter. According to the SAE EV AC Charging Power Levels, they can be classified as below [65]:

- Level 1: 120 VAC, 1-phase, 12 A/16 A depending on the circuit ratings. This system can be used with standard 110 V household outlets without requiring
any special arrangement, using on-board chargers. Connectors such as NEMA 5–15, SAEJ1772 are generally used. Charging a small EV can take 0.5–12.5 h. Suitable for overnight charging.

- Level 2: 240 V, 1-phase, 60 A and 14.4 kW Level 2 charging uses a direct connection to the grid through an EVSE. On-board charger is used for this system. This system is used as a primary charging

**Figure 3.** Graphical comparison of different charging levels.

**Figure 4.** Publicly accessible (a) slow charger and (b) fast charger stock by country, 2016 (number of units).
method for EVs. IEC 62196, IEC 60309, SAEJ1772, IEC 62198-2-Mennekes and 62198-2-Same connectors are generally used by this type of chargers

- Level 3: 400 V, 3-phase, 32–63 amp and power rating greater than 14.4 kW system uses a permanently wired supply dedicated to EV charging. IEC 60309, Magne charge, IEC 62198-2-Mennekes and 62198-2-Same connectors are generally used. ‘Fast chargers’ – which recharge an average EV battery pack in no more than 30 min, can be considered level 3 chargers. All level 3 chargers are not fast chargers though. Figure 3 shows the AC charging characteristics defined by different organizations (Table 2).

3.2.1.2. DC Charging System. DC systems require dedicated wiring and installations and can be mounted at garages or charging stations. They have more power than the AC systems and can charge EVs faster. As the output is DC, the voltage has to be changed for different vehicles to suit the battery packs. Modern stations have the capability to do it automatically. All DC charging systems have a permanently connected EVSE that incorporates the charger. Connectors which are generally used in this type are SAE J 1772 Combo, CHAdeMO [70] and IEC 62196 Mennekes Combo. Their classification is done depending on the power levels they supply to the battery [71].

- Level 1: The rated voltage is 450 V with 80 A of current. The system is capable of providing power up to 36 kW.
- Level 2: It has the same voltage rating as the level 1 system; the current rating is increased to 200 A and the power to 90 kW.
- Level 3: Voltage in this system is rated to 600 V. Maximum current is 400 A with a power rating of 240 kW. Figure 3 shows the DC charging characteristics.

For the current EV systems, on-board AC systems are used for the lowest power levels, for higher power, DC systems are used. DC systems currently have three existing standards: Combined Charging System (CCS): 50 kW, CHAdeMO [72] (CHAarge de MOve, meaning: ‘move by charge’): 120 kW and Supercharger (for Tesla vehicles).

Table 3 shows a comparison between various models of EVs and PHEVs, battery, motor capacity, full charge time and type of charging, etc. available for the model.

3.3. Control System and Safety Aspects Related to PVCS

3.3.1. Control System Aspects

It is worthwhile to mention the fact that from distribution (consumer side) and grid (supply side) point of view the penetration of solar PV and EVs would further render the voltage fluctuations, frequency mismatching, and power quality issues, etc. To cater this situation different optimization models have been proposed so far [73,74] and the problem will further simplify if we look into the coordinated, well optimized and properly scheduled [75] use of PV and EVs in present power system scenario. The optimal size of local energy storage for a Plug-in Hybrid Electrical Vehicle (PHEV) charging facility and control strategy for its integration with PHEV charging stations and a solar PV system is proposed in [76–78].

Typically, a battery charger has two stages: an AC-DC stage to rectify the grid AC voltage with power factor correction (PFC) and a DC-DC stage for regulating the battery currents and voltages [79]. A PWM DC/DC Converter for 6.6-kW EV Onboard Charger is proposed in [80], the scheme has a similar structure as of conventional resonant converters, the only difference is that the controller uses PWM technique [81] in place of a resonant controller. By PWM technique, low-efficiency operation and no-load regulation problems due to extremely high-frequency and low-frequency, respectively, can be avoided as is the case with resonant converters.

Substantial reliability of service connection to the EVs and charging stations is the utmost requirement of the modern charging system (i.e. smart charging system) [82,83]. General customer’s mandates are faster charging time and longer range, the two entirely conflicting needs. EV charging station can negotiate with the vehicle to let the charging system know how much power is available at the station, and safely enable the power only when the connection is verified safe [84]. The simple act of plugging in and charging a car becomes much more complicated when additional features begin to demand more processing power and sensing technologies.

Figure 5 represents an EV Advanced Metering Infrastructure (EVAMI) operation in the internet cloud-connected network. This Onsite Charging System (OCS) consists of an electric vehicle charging station (EVCS) and a Data Concentration Unit (DCU). The function of CS is to serve EV owners in car parks and other similar areas. Generally, it handles the initialization and termination of the charging session. During the charging period, the OCS monitors the charging status and updates the meter reading. It also monitors the health status of the CS. The DCU is a PLC internet gateway which supports TCP/IP communication and connects the OCS to the UIMS. In this work, PLC is adopted in order to furnish the captioned features into both the EVCS and DCU. Smartphone also has an active role in the EV – EVSE communication [86].
| Standard                                                                 | Scope                                                                 |
|------------------------------------------------------------------------|----------------------------------------------------------------------|
| IEC 61851: Conductive charging system                                   | Defines plugs and cables setup                                      |
| IEC 61851: Conductive charging system                                  | Explains electrical safety, grid connection, harmonics, and         |
| IEC 61851: Conductive charging system                                  | communication architecture for DCFC station (DCFCS)                 |
| IEC 61851: Conductive charging system                                  | Describes digital communication for controlling DC charging         |
| IEC 61851: Conductive charging system                                  | Defines general requirements of EV connectors                        |
| IEC 61851: Conductive charging system                                  | Explains coupler classifications for different modes of charging   |
| IEC 61851: Conductive charging system                                  | Describes inlets and connectors for DCFCS                           |
| IEC 61851: Conductive charging system                                  | Describes C5 general requirements                                   |
| IEC 61851: Conductive charging system                                  | Explains sockets and plugs sizes having different number of pins   |
| IEC 61851: Conductive charging system                                  | determined by current supply and number of phases                   |
| IEC 61851: Conductive charging system                                  | defines connector color codes according to voltage range and         |
| IEC 61851: Conductive charging system                                  | frequency                                                           |
| IEC 61851: Conductive charging system                                  | Explains electrical installations for buildings                     |
| IEC 61851: Conductive charging system                                  | Defines AC charging connectors and new Combo connector for DCFCS    |
| IEC 61851: Conductive charging system                                  | Explains communication medium and criteria for connecting the       |
| IEC 61851: Conductive charging system                                  | EV to utility for AC level 1 & 2 charging                           |
| IEC 61851: Conductive charging system                                  | Defines messages for DC charging                                     |
| IEC 61851: Conductive charging system                                  | Explains total EV energy transfer system, defines requirements for   |
| IEC 61851: Conductive charging system                                  | EVSE for different system architectures                             |
| IEC 61851: Conductive charging system                                  | Defines EV safety guidelines                                         |
| IEC 61851: Conductive charging system                                  | Being developed                                                     |
| IEC 61851: Conductive charging system                                  | Standard for vehicle battery adapters                               |
| IEC 61851: Conductive charging system                                  | Standard for EV supply equipment                                     |
| IEC 61851: Conductive charging system                                  | Part 1: general requirements for conductive charging system of EVs |
| IEC 61851: Conductive charging system                                  | Requirements of EV to connect an AC/DC supply in conducting modes   |
| IEC 61851: Conductive charging system                                  | EV charging station based on AC supply                               |
| IEC 61851: Conductive charging system                                  | Part 1: Details of general requirements for EV conductive charging  |
| IEC 61851: Conductive charging system                                  | EVs requirements for conductive connection to an AC/DC supply        |
| IEC 61851: Conductive charging system                                  | EV conductive charging system AC/DC EV charging station            |
| IEC 61851: Conductive charging system                                  | Basic function of EV quick charger                                  |
| IEC 61851: Conductive charging system                                  | Efficiency test method of an EV charging system                     |
| IEC 61851: Conductive charging system                                  | DC EV charging station based EV conductive charging system          |
| IEC 61851: Conductive charging system                                  | To control the DC charging, digital communication between EV and    |
| IEC 61851: Conductive charging system                                  | a DC EV charging station                                            |
| ISO 871: Electric road vehicles road operating characteristics        | Electric road vehicles reference energy consumption and range test  |
| ISO 871: Electric road vehicles road operating characteristics        | procedures for passenger cars and light commercial vehicles         |
| ISO 871: Electric road vehicles road operating characteristics        | Electrically Propelled Road Vehicles Dimensions and Designation of  |
| ISO 871: Electric road vehicles road operating characteristics        | Secondary Lithium-ion Cells                                          |
| ISO 871: Electric road vehicles road operating characteristics        | ElectricVehicle Wireless Power Transfer (WPT) Systems               |
| ISO 871: Electric road vehicles road operating characteristics        | SAE ElectricVehicle Inductively Coupled Charging (STABILIZED Jun 2014) |
| ISO 871: Electric road vehicles road operating characteristics        | Restrict the Frequency Electric Field and Magnetic Field Exposure to |
| ISO 871: Electric road vehicles road operating characteristics        | Outside Human                                                       |
Our system must have the following listed features [87]:

- Wi-Fi enabled EV charging: real-time monitoring [88] and control with a home or office charging station; remotely schedule time with public stations, etc.
- Contactless prepayment and media-rich user interfaces.

- Cloud communications and accurate energy measurement.
- Smart, low-cost ac charging system for electric vehicles.

Previously, the work using different control strategies for energy storage sizing, energy flow between the PV panel, battery and switched reluctance motor (SRM),
needed. EVSE refers to charging stations and other fixtures outside of the EV that provides the controlled, safe, and reliable operation of the vehicle charging system (Figure 6).

3.3.2. Safety Aspects

The safety standards that should be complied by the chargers are as follows: (i) SAE J2929 is the standard for Electric and Hybrid Vehicle Propulsion Battery System Safety. (ii) ISO 26262: Road Vehicles – Functional safety (iii) ISO 6469-3: Electric Road Vehicles – Safety Specifications – Part 3: Protection of Persons Against Electric Hazards (iv) ECE R100: Protection against Electric Shock (v) IEC 61000: Electromagnetic Compatibility (EMC) (vi) IEC 61851-21: Electric Vehicle Conductive Charging System – Part 21: Electric Vehicle Requirements for Conductive Connection to an AC/DC Supply (vii) UL 2202: Electric Vehicle (EV) Charging System Equipment (viii) FCC Part 15 Class B: The Federal Code of Regulation (CFR) FCC Part 15 for EMC Emission Measurement Services for Information Technology Equipment. (ix) IP6K9K, IP6K7 protection class. (x) −40 °C to 105 °C ambient air temperature.

3.3.2.1. J1772 Coupler.

The J1772 Standard EV coupler [103] is designed for 10,000 connections and disconnections with exposure to dust, salt, and water; is able to withstand a vehicle driving over it, and is corrosion resistant. The J1772 Standard and National Electrical Code (NEC) requirements create multiple safety layers for EV components [104], such as:

Figure 5. EVAMI overview [85].
installation of surge protective devices. Protective measures against direct lightning and LEMP must be integrated to provide better protection results [107].

### 3.4. Social Aspects

The acceptance of a new and immature technology, along with its consequences, takes some time in the society as it means a change of certain habits [108]. Using an EV instead of a conventional vehicle means a change of driving patterns, refueling habits, preparedness to use an alternative transport in case of low battery, and these are not easy to adopt.

Deployment of renewables faces many problems connected to social acceptance. In the concept of social acceptance of renewable energy innovations three dimensions are distinguished (Figure 7): (1) socio-political acceptance concerns the acceptance of decisions about the institutional framework; this framework can, in turn, create favorable conditions or impede the acceptance in the other two dimensions; (2) community acceptance and (3) market acceptance [109].
3.5. Commercialized Business Model of PVCS

It is important to have a business model of PV-EV charging station in order to make the best use of economic performance [110]. Solar charging stations appear as the ideal option for those who cannot afford to purchase a solar home system (SHS). Solar charging stations increase the income of the station owner (which can be the same person who previously sold kerosene). The SCS can also be managed by the community. In a centralized business solution, it is easier to have access to loans and credit and to collect batteries and recycle them. Solar charging stations require a lower initial investment (at least if the cost per person is considered) and a lower operation and maintenance cost [111]. The opportunity to achieve economies of scale and the possibility to have lower prices for those who have a lower income is an advantage [111]. When the station is managed by an entrepreneur or the community, the excess profit can be used to fund other community’s needs, such as electrifying schools and health centers [112]. This entrepreneur is the key factor in the project sustainability, their main purpose should be to provide the best service as possible to the end-users [113].

According to the data, the parking duration time of vehicles around office buildings is usually much longer than the charging time they need, which means that they do not need to be charged as soon as they arrive. Considering this fact, it is obvious that the combination of the parking and charging demands will produce a more effective mechanism. Hence, a typical operation mode for a commercialized PVCS is shown in Figure 8.

According to the above policies, the economic benefits of the commercialized PVCS mainly consist of the charging service fees, the parking service fees, the profit of the sold PV energy (sold to EVs users or the grid [114]), and the subsidies of PV energy from the government. Therefore, it is possible that the investors of the PVCS will make a considerable profit if the charging demand is well scheduled [115].

4. Available Solar Charging Technologies

Solar Photovoltaic (SPV) System is considered as an important resource, gradually becoming more affordable and proving to be more reliable than utilities. A solar installation will charge your electric car just as it will supply energy for the rest of your home appliances. Even a small solar array with only 10 panels (of typical rating) can provide enough power to charge your vehicle’s battery. It is here to note that the solar PV charging system requires solar panels with EV charger [116]. The integration of solar photovoltaic (PV) into the electric vehicle (EV) charging system has been on the rise. Numerous review articles have published so far, on EV charging using the utility (grid) electric supply, but the detailed comparison of different EVPV charging strategies specifically have not been covered yet. With the growing interest in this subject, this section summarizes and update all the related aspects on PV-EV charging, which comprises the power converter topologies, charging mechanisms and control and optimization for both on-grid and off-grid/hybrid systems. Figure 9 shows a typical on-grid solar PV-EV charging station. Possible architecture combinations for a solar EV charger [57] and the operation in different modes is described [117] with the help of following different charging strategies:

4.1. Standalone-Backup Power PVCS

A stand-alone photovoltaic generation system [118] is a complete set in which components are interconnected for directly converting solar irradiance into electricity. The components are PV generator, battery, charge controller, inverter, and the system load. The system is a PV power generation plant which is not connected to any utility grid. Stand-alone PV system [80] concepts found in the market are as follows: – Solar Home System [119] (Figure 10(k)): Photovoltaic stand-alone, for V2H/H2V application (Figure 10(j)), that can fully charge at home [120], the BEV overnight or can supply the residential load through EV battery [121–124]. All consumers and PV generator are coupled to the DC voltage – Small AC local grid with coupled components: this PV technology appeared due to the desirable supply (minimum power) AC loads by DC power sources and to charge the battery on the DC from different sources. – Modular AC coupled systems: more flexible PV systems with modularly structured components are achieved by coupling all consumers and PV generator on the AC [24].

![Figure 7. Three dimensions of social acceptance of renewable energy innovations [86].](image)
Due to the variability in the nature of PV generation, a grid connection is essential to guarantee the reliable electricity supply for charging the vehicles. Generally, employee’s vehicles remain there for 6–9 h at the parking area and the long charging period results in less EV charging requirements and also paves the way for grid support through vehicle-to-grid (V2G) technology (Figure 10(h)) [57]. While in the off-grid system, vehicle-to-home (V2H) technology is possible.

4.2. Solar Powered EV Charging System

Electric vehicle (EV) charging from SPV offers a sustainable way for recharging the car batteries. Workplaces such as factories, office buildings, and industrial areas are perfect places to enable solar EV charging where the area under the building’s rooftops and car parks can be utilized to install photovoltaic panels. The generated power is utilized directly for EV charging in an EV-PV charger, without the need for the storage system.
The literature on solar energy for charging the EVs is much advanced and diverse. This is because the electricity produced by solar PV provides more flexible integration with the existing grid. Among the various strategies, one is to charge the EV directly using the principle of ‘charging-while-parking’ to supplement...
the more common practice i.e. ‘charging-by-stopping.’ Subsequently, the EV can be getting charged by means of the integrated PV-grid system whereas at the same time EV owner involves in other activities. P. J. Tulpule et al. have listed several advantages of the PV powered charging station [125]. As the charging is being done during the hours of daylight, when the demand and tariff are on their peak, the substantial cost savings is accomplished. On top of that, the roofed parking facility provides free housings from the sunlight and raindrops, the scheme is very much favorable in hot climate regions. Owing to these benefits, the on-grid PV system is more favored one than other renewable-based generations. A. R. Bhatti et al. [126] submit a case study on charging by a standard power grid system, on-grid PV system, and off-grid PV (standalone) system with energy storage unit. Moreover, a large-scale deployment of EV chargers is examined in a medium-sized Swiss city where solar carports can be spread out over whole parking areas. The evidence were found that the solar energy could provide the energy demand about 14–50% of city’s public transport sector. Also, S. Letendre et al. suggested a simple technique to approximate the cumulative capacity that can be supplied by an on-grid PV and V2G (vehicle-to-grid) stations in the California market [127]. W. Kempton et al. in another work, discussed the application of PV electricity and storage [128]. The conclusion is that the on-grid PV system is more profitable compared to the standalone PV and standard grid charging systems.

4.3. Solar Powered DC Fast Charging System

A bi-directional DC-DC electric vehicle (EV) charger is positioned between the high-voltage DC bus of a PV system and the EV battery [129,130]. In addition, to charging the EV battery from the PV or the grid at a faster rate, the fast changes in PV power output to the battery can be diverted by the charger itself. Hence, the rate of change of inverter output power reduces to a level below the existing grid resource ramp rate. The EVs have inbuilt direct DC fast charging port and consequently, no inverter is needed between PV and EV. But in the on-grid system, the inverter is needed between PV and power grid [131].

4.4. Solar Rooftop or Ground Mounted System

It is a most widely used and practically accepted system in the world. In this system, the solar panels are installed on top of a roof (of a residential, commercial buildings and structures) or the land area can be utilized as ground mounted system for the purpose of electrical or thermal energy generation. As far as the electrical generation is concerned, the system includes photovoltaic modules, mounting systems, cables, solar inverters, and other electrical accessories. The rooftop system is small typically 5–20 kilowatts (kW) on residential buildings and 100 kilowatts (or more) mounted on commercial buildings [132] while the ground-mounted system is sometimes very large ranging in megawatt capacities. A study for the installation of a 6Kwp grid tie solar system capable of producing 25 units is given in [133].

There are three classifications based on grid interface: Off-grid, On-grid solar rooftop system, and Hybrid systems.

4.4.1. On-grid Solar EV Charging System

Solar PV panels installed on a roof of a building supplying the individual load as well as connected to utility grid power is called on-grid solar rooftop system [134]. The output of solar PV is directly connected to distribution systems via grid-tied inverters and cannot operate without grid reference voltage and frequency. Although it is designed to island the PV system under abnormal grid conditions. There is no need of battery bank, source and load variations are compensated by grid i.e. increased load demand is fulfilled by taking the supply through the grid and when load demands are low and solar is available then surplus energy can be sent back to the grid.

This article investigates the integration of Photovoltaic (PV) solar power, electric vehicles (EVs) and battery energy storage into a grid-based charging station [135,136]. The goal is to optimize the share of Renewable Energy (RE) sources in the existing power grid to provide as much of the charging energy as possible. As the name is grid-connected, the facility of charging during cloudy or rainy seasons can be exploited. In excess generation condition, the grid connection also permits exporting power from PV to the grid. It is recommended that the second-life lithium-ion batteries must be incorporated into the system to work as an energy buffer and provide emergency backup in a shortage of the grid supply.

Grid-tied rooftop/ground mounted solar system produces electrical energy and this energy is fed to the utility grid with the help of solar hybrid inverter. The design of solar inverter is such that it converts the solar generated direct current (dc) into alternating current (ac) and at the same time maintaining the utility grid frequency. After that, the ac output power a 50/60 Hz is fed to the commercial electrical grid. The consumers can get a discount on their own electricity by supplying excess units (kWh) to the commercial power distribution company with help of their own charging station and could make a revenue on their monthly electricity bills [133].

The interaction of electric vehicles in the smart grid and integration of the renewable energy sources using EVs is presented in [18].
4.4.2. Off-grid Solar EV Charging System

Figure 10(c) shows EV charging station deploying standalone PV solar on the rooftop at the parking lot [137]. Solar PV panels installed in a particular area for supplying the individual owner EV or residential/commercial loads and is not connected to any utility grid is called off-grid solar power system [138]. A battery bank is normally necessary to guarantee the constant uninterrupted power supply in order to meet the fluctuations in input side due to the intermittency in solar radiation falling on the panel. Ultimately the off-grid charging unit is a standalone power system forming a micro-grid to feed the load (EVs) during the daytime without battery bank [139,140]. The off-grid photovoltaic system is a very good choice for supplying distant areas or depopulated areas that are not connected to the grid [141].

4.4.3. Hybrid Solar EV Charging System

The system is connected to grid along with a battery backup. During abnormal grid conditions, they can operate in island mode without grid reference voltage and frequency [45]. Hybridization means charging the EVs from more than one sources working in conjunction with one another. One such system is solar–wind system etc. proposed in several published papers [142]. The solar–wind hybrid system can work during the day when solar is present and also during night hours as the mostly wind is available in the night time. Figure 10 shows different modes of operation of figure 9 PVCS [143–145].

4.5. Vehicle-Integrated PV (ViPV) System

There is a much work regarding ViPV prototypes, concepts and studies available, but the practical utilization of power generated by the ViPV system, of course, the very crucial point for the concerned people. The basic design of Vehicle-Integrated PV system defines the EV (or HEV) car's body is embedded with the solar photovoltaic material. Solar cells might be embedded into the chassis part exposed to sunlight like the hood, roof and maybe the trunk depending on a car's design. 'This would allow a hybrid vehicle to be partially powered using solar energy,' says Letendre. Hence, vehicle itself resembles a small solar power plant and hybrid automobiles converted into even more environmentally friendly. Hybrid vehicles use an internal combustion engine and electric motor both as a source of supply to the vehicle. Evidently, the sunnier the climate, the more the share of the contribution that solar cells might make to fuel efficiency. A typical estimate shows that a hybrid car fitted with solar cells of 500 watts embedded, in the sunniest region of the nation, might conceivably generate 1051 kW of energy per year, and account for around 5100 miles travelled – one-third of yearly miles travelled by taking an average annual mileage of 15,000. It merely accounts for 850 miles driven per year in a very cloudy region. Annually, the saving in the fuel cost with the ViPV system would be relatively marginal. In comparison with gaseous fuel prices which are now well over Rs. 35.81/liter, the ViPV cars on average would take more than five years to pay back [88]. Illustrating the fact that the amount of electrical energy required in state of the art vehicles is cumulating day by day, a ViPV system tags a supplementary source of power not only to charge the battery during vehicle standstill but during vehicle operation as well. Basically, it is a dynamic source which can supply additional power for electronic control units, actuators, displays, heating, ventilation and air conditioning units, and other electronic equipment such as 110 or 230VAC power converters, refrigerators and even microwaves, etc. [151].

An alternative technique is the paintings on the car surface with the light resistive material. The thin film photovoltaic solutions technology is cheap and can be painted on the car's body [152]. The system electrical efficiency of the commercially available thin film technology is merely 4–6%. And in the laboratory and research work, the thin film has efficiency beyond 20% and for organic materials, it is about 10% [153].

Furthermore, when the vehicle is parked, the unused photovoltaic generated electrical energy can supply standby currents and ventilation systems to make the interior cooler in hot weathers. By pre-cooling, the interior will demand lesser fuel consumption and GHG emissions (less cooling work for the air conditioning) and safeguard the interior equipment (less thermal stress for trim and upholstery) [154].

4.6. Solar Parking Lot: (A Concept of Workplace Daytime Charging Without the Need of Battery Bank)

Workplaces like offices, factories, industrial areas, and commercial buildings are perfect places to facilitate solar PV-EV charging where the building's rooftops and car-parking shed can be mounted with photovoltaic (PV) panels [155]. Essentially a photovoltaic parking lot provides the on-site energy generation for supplying the electric car batteries [156] and hence the power is directly available for EV charging through an EV-PV charger, without necessitating the energy storage [57]. The system is becoming increasingly popular in areas above the surface and multi-story car parking lots. Otherwise, the area above a car park is an unexploited brownfield site that is exposed to use as renewable energy generating unit that can enhance the car parking experience as an environmental performance of the asset.
Studying the case of any solar PV-EV car parking lot charging station located at workplaces. Most of the vehicles are parked throughout the day at workplace parking spaces and these can be charged from the solar energy at normal charging rate using photovoltaic (PV)-based charging facility. Which can help to reduce the load and emissions from the power grid but also affects the cost of charging [157].

In the countries where, at the managerial level, particularly in smaller companies, the daytime working hours are typically 11 h a day and 6 days a week. Some of the companies and MNCs/Government offices and tend to follow a 5-day, 8–9 h per day working schedule. These observations show that vehicles are typically parked for a sufficiently long time during the day such that it is possible to use solar energy directly to charge the PEVs at the workplace without using large energy storage. This PV-based parking garage concept can be implemented in tropical countries and the countries having long duration of sunshine hours with considerable amount of solar potential easily [158].

The big advantages of a carport come from the fact that the space beneath the panels is still usable. Your parking experience is much better than parking out in the open, although not as much as a full garage, depending on the size.

4.7. Solar Island: Small Island Developing States (SIDS)

Islands are generally disconnected from mainland electricity grids and are especially vulnerable to price fluctuations for imported fossil fuels. So, to overcome such challenges islands such as Small Island Developing States (SIDS) can exploit the clean and cost-effective renewable energy technologies, and take part in mitigating the global climate change effect, through sustainable development of renewable energies. Also, provide an attempt to foster economic progress, mitigate environmental effects and hence reduce their reliance on imported fossil fuels like coal, gasoline, diesel, etc. The recently advanced concept offers a geographical landscape which is quite feasible for distributed generation in order to cater the end-users energy demands that are situated in isolated areas. Many times, this distributed generation is in fact accomplished through on-grid/off-grid/hybrid solar photovoltaic (PV) systems [159].

Being tropical, islands have plenty of solar potentials to prove a very high feasibility for the development of solar charging schemes as presented in [160] for Indonesian islands Sumatra, Java, Nusa Tenggara Timur, Nusa Tenggara Barat, etc.

The solar PV supported micro-grid is to be the best practically viable option designed for small and remotely located island power systems for EV charging station [161]. Lakshadweep islands are the union territories of the Indian subcontinent. The main source of electricity in Lakshadweep islands is diesel generators, the diesel being transported from the subcontinent. Due to higher cost of energy, the islands are proving to be excellent test beds for the introduction of new technologies and becoming so-called renewable energy islands to satisfy their energy demand mainly from indigenous and renewable energy sources such as solar photovoltaic (SPV)-based power generation of electricity in particular for balance solution to the energy problems of Lakshadweep Island [162].

The International Renewable Energy Agency (IRENA) launched its SIDS Lighthouses Initiatives at the Climate Summit in New York on 23 September 2014. The focus for 2016–2017 will be on reinforcement the present Global Renewable Energy Islands Network (GREIN) clusters on renewable energy roadmaps, power grid integrations, etc. [163].

5. Economic and Environmental Analysis

Today, the world is facing two big transitions in generation and transportation systems simultaneously. The existing system is fossil fuel-based i.e. power generation from coal/nuclear etc. and transportation from oil and gas as propulsion power. And to phase out this by renewables completely, there are many economic and environmental challenges too. In spite of replacing the whole system, it is more economical to scale up the share of renewable energy in the present generation system [164].

5.1. Impact on Environment

One of the main factors that propelled the increase in EVs’ popularity is their contribution to reducing the greenhouse gas (GHG) emissions. Conventional internal combustion engine (ICE) vehicles burn fuels directly and thus produce harmful gases, including carbon dioxide and carbon monoxide. HEVs and PHEVs have IC engines, their emissions are less than the conventional vehicles.

If EVs add excess load during peak hours, it will lead to the operation of such plants and will give rise to CO2 emission. With renewable sources integrated properly, which the EVs can support strongly, the emission from both power generation and transportation sector can be reduced. Over the lifetime, EVs cause less emission than conventional vehicles. This parameter can be denoted as well-to-wheel emission and it has a lower value for EVs.

According to the Paris Agreement enforced in November last year, the objective of limiting the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit
the temperature increase to 1.5 °C above pre-industrial levels [165]. The automobile is one of the main contributors to greenhouse gases. India is trying to make itself less polluting and reduce carbon footprint. It has internal as well as an external commitment for the same.

While most people assume that the CO₂ emissions of an EV are zero that is not the case. This is because electricity production by itself results in CO₂ emissions. This is especially true in those countries where large amounts of fossil fuels like gas and coal are used in the generation of electricity. EV uptake will result in increased demand along with an increase in absolute electricity industry CO₂ emissions unless the electricity used to recharge EVs is sourced from renewable energy. According to an estimate, the net CO₂ emission is 910 g/kWh to 950 g/kWh during the period of 2001–2002 to 2009–2010 from thermal power plants in India [166]. The total GHG emission from the natural gas combined cycle (NGCC) thermal power plant was 584 g CO₂ eq/kWh electricity generation, whereas, in case of imported coal, it was 1127 g CO₂ eq/kWh electricity generation.

India accounts more than 17% of the world’s population, i.e. about 1.2 billion people. Hence, it is very challenging for India to provide sufficient energy supplies to all the consumers at an equitable cost. India’s energy use and installed electricity capacity have increased by 16 times and 84 times, respectively, in the last six decades [167]. With the rapid decrease in the price of PV modules, the long-term economic benefit of solar charging [168] can be tremendous over its localized harmful effects [169,170].

In India, about 70% of overall electricity generation is based on thermal energy. Huge amounts of non-renewable sources such as coal are being consumed for the production of thermal power which leads us to degradation of the environment. Hence, it is imperative to shift to renewable sources of solar energy for the generation of electricity. At present scenario generation using solar power is perceived be too costly. Installation of solar equipment for the typical household is difficult as enough technical awareness is lacking in choosing suitable components with appropriate ratings. Also, India generally has a strong dependence on the overseas companies for technology as there is hardly any research happening in this direction. The Indian automaker spends around 1–2% of their revenue on R&D. The growth in electric vehicles in these markets has been mainly driven by incentive and tax relaxation. However, the cost of the lithium-ion battery is going down significantly and expected that in the coming few years, EVs will become as competitive as ICE engine vehicles. Currently, the biggest roadblocks in terms of increasing the penetration of electric vehicle are the price and range of the battery [171].

It is shown here that many countries have a common goal to overcome the global warming and pollution-related problems and the remedy they are focusing is to adopt renewable energy worldwide. One important aspect is that even though solar charging of EVs has all the environmental benefits over any other type of charging methods available, it is not feasible economically to think about the 100% deployment of renewable-based charging system worldwide. Among the various reasons, the important ones are fossil fuels are the backbone of existing grid-connected power system, and also constraints on large-scale production and installation of PV modules restrict its generalized acceptance worldwide. In view of the present situation, the share of renewable energy must be increased sustainably in today’s power generation methods. The best-recommended practice is to have on-grid solar charging system having maximum share of solar energy and the rest is fulfilled by grid supply. The other option is an off-grid standalone system which is costlier but have no issue of DC interconnection to the grid, flexibility with design and can be installed anywhere.

On the other hand, EVs require energy storage charging that creates a new challenge to the utility grid interconnection and ultimately the use of EVs also becomes a cause of pollution. Hence, reduction of the greenhouse gas (GHG) emissions from electricity production have been a greater desire for energy efficiency and alternative renewable energy resources. EV charging from the power grid with coal-fired generation may cause EVs to have higher well-to-wheel emissions than ICEVs. EVs may not prove to be that much environmentally friendly if they are charged from the power grid relying on fossil fuels for producing power. In the recent years, many countries have invested large amounts in renewable energies such as solar and wind to meet the need of increasing demand and avoid full dependency on fossil fuels. Furthermore, the use of renewable energy for EV charging can also help to reduce the impact of the additional load in the form of EVs on the grid. PEVs have zero emissions from driving if the electricity supplied is generated from renewable resources such as solar energy.

Comparing the energy efficiency of different internal combustion engine vehicles (ICEVs) is easy; just compare vehicle-km for each vehicle per liter of petrol used, for example. But for EV vs. ICEV comparisons, both petrol and electricity must be converted to primary energy terms – for instance, crude oil for ICEVs and coal for electricity from coal-fired electric plants. But a difficulty arises when converting electricity to primary energy for different non-fossil fuels. For thermal electricity production in nuclear or geothermal power plants, primary energy is always calculated from the heat energy used to generate the electricity, just as for fossil fuel power stations.
This problem can be avoided if ICEV vs. EV comparison is done on the basis of \(\text{CO}_2\), or more generally, GHG emissions usually expressed as equivalent \(\text{CO}_2\) (\(\text{CO}_2\)-eq). But then a new problem emerges: in nearly all published comparisons, non-fossil fuel electricity (RE and nuclear), it is assumed that these sources generate zero GHG emissions, that they are ‘zero carbon’ sources. [164] But if we compare to coal’s Carbon dioxide (\(\text{CO}_2\)) emission of 975 g per kilowatt-hour (kWh), the use of PV emits about 50 g of \(\text{CO}_2\) per kWh [38].

**5.2. Impact on Economy**

From the perspective of the EV owners, EVs provide less operating cost because of their superior efficiency [172], it can be up to 70% where ICE vehicles have efficiencies in the range of 60–70%. The current high cost of EVs is likely to come down from mass production and better energy policies which will further increase the economic gains of the owners. V2G also allows the owners to obtain a financial benefit from their vehicles by providing service to the grid. The power service providers benefit from EV integration mainly by implementing coordinated charging and V2G. It allows them to adopt better peak shaving strategies as well as to integrate renewable sources. EV fleets can lead to $200–$300 savings in cost per vehicle per year.

Though electric vehicles (EVs) have been around since the late 1800s. They were very popular and a number of EVs were sold until about 1918. For example in the year 1900, about 4200 automobiles were on the road, out of which 38% were electric, 22% gasoline powered, and 40% steam [173]. With the advancement of gasoline engines, due to low cost of gasoline at that time, and the invention of electric starter for the internal combustion engines, the interest in EVs completely declined.

Meanwhile, there is a major move toward large-scale decentralized renewable energy production through photovoltaic (PV) system due to dropping the cost of PV panels. The combination of EV and PV provides a unique opportunity for sustainable charging of electric vehicles. Many countries have set their benchmark as 2030–2050 and making their policies accordingly. German Act on Granting Priority to Renewable Energy Sources (Erneuerbare Energien Gesetz, EEG), the renewable energy share to be reached up to 40–45% by 2025 and then to be raised further to 55–60% by 2035 [174]. China is the world leader in both the photovoltaic production and electric vehicle market and ranked number one PV manufacturing nation with roughly 58% of global market shares overall, and of course, faces economic impact [175]. The top five solar cell suppliers in progressive order are China, Taiwan, the United States of America (U.S.A.), Japan, and Germany in the world [176]. Taiwan also expecting 3.1 GW capacities by 2030 [177]. France has too set a target for renewable energy to signify a 23% share of total energy uptakes by 2020. With this effect any new building shall be a positive energy building and that the utilization of rechargeable electric and hybrid vehicles (HV) should represent 30% of all vehicle sales by 2020 [178]. According to FAME India mission of Indian Government, there would be 200,000 EV on the roads by 2020 [52].

Several studies in different parts of the world discussing different aspects of economic [179] and environmental issues/benefits highlights the significance of charging of EVs from solar panels. Such a study of Northeast Asia (NEA) utilizing the abundant renewable resources. From an environmental viewpoint, renewable energy has a substantial amount of potential to decarbonize the NEA power system. Renewables’ share grows from 20% in the Base case to 47%, resulting in the \(\text{CO}_2\) emissions reductions from power generation of 36%. \(\text{CO}_2\) emissions are reduced by more than 35% in the China nodes as the Mongolian renewables replace carbon-intensive coal-fired generation. On the other hand, the results show relatively modest effects in Japan. Massive renewables significantly contribute to saving fuel costs; however, the benefits are offset by the initial costs for the renewables and transmission lines. The massive deployment of renewables changes the cost structure to be more capital intensive due to the huge investments required. The relevant planning organizations need to carefully consider how to secure such large investments, taking into account long-term energy prices, capital costs, and environmental policy trends in order to assure that implementation will be beneficial [180].

**6. Conclusions**

Solar PV and EVs are two sectors that turn out to be the future mode of transport and have a considerable potential for reducing \(\text{CO}_2\) emissions and fossil fuel consumption. Unfortunately, both of these has barriers to very large-scale deployment. For PV, its variable nature and the concentration of electricity output in the daytime restricts its contribution in meeting a large fraction of typical electricity demand. Though EVs provide a clean, efficient, and noise free means for commuting for when compared with the gasoline vehicle. This paper has presented in-depth review of solar powered EV system, various aspects such as charging infrastructure, methodology, and EV energy management has been discussed in detail. However, numerous challenges still need to overcome. The key challenges include the cost and performance of the battery storage systems that restrict their economic consumption. And also has a limited utility as well owing to driver range anxiety and...
charging infrastructure access. The driver range anxiety significantly effects the selected utility and may vary subject to the average high and low range anxiety drivers. According to section four, various charging opportunity options illustrated deploying a particular charging infrastructure seems to overcome the range anxiety impact and increase utility, as projected. Across these scenarios, the potential gains of different solar PV-EV charging technologies have highlighted, yet not cater the vehicle utility and infrastructure cost relationship for affordable, more realistic models setup. Hence, great future prospects are there regarding these mentioned roadblocks to mitigate out. Social barriers also check the wide adoption of this technology, particularly in developing countries. People have a tendency to resist new technologies that are considered unaware/unaccustomed, consequently, the effective way will be the policy-making decisions that show their critical concerns. There are still a number of technical problems to overcome, particularly in the area of power electronics i.e. bidirectional converters and motor drive propulsion systems in EVs and PHEVs. Of course, several technologies are on the horizon to be adopted in the next generations of automobiles, major obstacles must still be catered in the area of volume, weight, and cost to realize the desired performance and efficiency. Other related issues are manufacturability, consistency, safety, and robustness, and from section five, the most significant factor from the customer viewpoint is the cost function. Barriers and challenges regarding direct DC PV charging of EVs are lack of equipment and application standards for dc distribution, security, and power protection device application, etc. Also, the robust ecosystem is not yet developed so far to sustain the use of dc in commercial level electrification. Despite these challenges, if both these technologies deployed together, the improved economic performance of EVs might be possible by the availability of daytime charging, increasing the distance travelled using low-cost electricity and potentially reducing the size of the battery. The best optimum feasible option is to set up different solar PV-EV charging stations in distributed form globally as different methods are signified in this paper. Accelerating the deployment of renewable energy and the electric vehicle will fuel economic growth, create new employment opportunities, enhance human welfare, and contribute to a climate-safe future.

**Nomenclature**

| Abbreviation | Definition                                      |
|--------------|-------------------------------------------------|
| AC           | Alternating Current                             |
| BEV          | Battery Electric Vehicle                         |
| CH₄          | Methane                                         |
| CO₂          | Carbon dioxide                                  |
| CS           | Charging Station                                |
| DC           | Direct Current                                  |
| DCU          | Data Concentration Unit                         |
| E            | East                                            |
| EJ           | Exajoules                                       |
| ESU          | Energy Storage Unit                             |
| EVAMI        | Electric Vehicle Advanced Metering Infrastructure |
| EVARC        | Electric Vehicle Autonomous Renewable Charger   |
| EVCS         | Electric Vehicle Charging Station               |
| EVSE         | Electric Vehicle Supply Equipment               |
| EV           | Electric Vehicle                                |
| EVI          | Electric Vehicles Initiative                    |
| FAME         | Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles |
| GHGE         | Green House Gas Emission                        |
| GREIN        | Global Renewable Energy Islands Network         |
| G2V          | Grid to Vehicle                                 |
| GW           | Gigawatt                                        |
| Http         | Hypertext Transfer Protocol                     |
| HV           | Hybrid Vehicle                                  |
| H2V          | Home to Vehicle                                 |
| I₃D          | Diode Reverse Saturation Current                |
| I₃L          | Cell Photo Current                              |
| IC           | Integrated Circuit                              |
| ICEV         | Internal Combustion Engine Vehicle              |
| IRENA        | International Renewable Energy Agency           |
| KCL          | Kirchoff’s Current Law                          |
| kWh          | Kilowatt-hour                                   |
| MNRE         | Ministry of New and Renewable Energy            |
| MPPT         | Maximum Power Point Tracker                     |
| N            | North                                           |
| NASA         | National Aeronautics and Space Administration   |
| NEA          | Northeast Asia                                  |
| NEMMP        | National Electric Mobility Mission Plan         |
| NGCC         | Natural Gas Combined Cycle                      |
| NH₃          | Ammonia                                         |
| NPE          | National Electric Mobility Platform             |
| NOₓ          | Nitrogen Oxide                                  |
| N₂O          | Nitrous Oxide                                   |
| OCS          | Onsight charging System                         |
| PEV          | Plug-in Electric Vehicle                        |
| PFC          | Power Factor Correction                         |
| P2G          | Photovoltaic to Grid                            |
| PHEV         | Plug-in Hybrid Electric Vehicle                 |
| PLC          | Programmable Logic Controller                   |
| PM           | Particulate Matter                              |
| PV           | Photovoltaic                                    |
| P2V          | Photovoltaic to Vehicle                         |
| PVCS         | Photovoltaic Charging Station                   |
| PWM          | Pulse Width Modulation                          |
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