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Evaluation of solar powered charging station and electric vehicle technologies

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Abstract- *Electric Vehicles (EVs) are fast developing in recent years in the world. They are a promising transportation sector in the future to reduce greenhouse gas emissions. Electric charging of EVs will impact the electric grid system and charging station infrastructures. Therefore, the technology of charging/discharging will be important critical for the success of EVs. In addition, renewable energy sources are a great relevant solution to supply clean electric sources for the grid system and EVs charging stations. Specifically, solar is one of the suitable energy sources for generating electricity to charge for EVs. This paper reviews the fundamental knowledge of solar PV-EV charging systems and deployment. The different control and operation methods are presented in this paper. The other aspects of EVs such as the charging station infrastructure, policy, and economics are also reviewed. The aim of this paper is useful to document and helpful to the students and researchers.*
Keywords *Electric vehicles, solar energy, charging system, environment, fast charging.*

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I. Introduction

Fossil fuels are important energy sources for both the transportation sector, power generation industry and economic development. Besides, fossil fuels are limited in nature; it leads to increasing costs and impacts unsustainable energy and economic systems. Burning fossil fuels generates greenhouse gases (GHGs) which highly impacts world climate change. Many solutions have been proposed to mitigate these problems. Specifically, the 21st Conference of the Parties [1] agreement was signed by 175 countries in Paris [2] to strengthen the global response to climate change. In the New Policies Scenario, the use of electric vehicles (EVs) would decrease GHG emissions of 230 Mt CO_2-eq (million tonnes of carbon dioxide equivalent). It means that cut down oil products by 127 Mtoe (million tonnes of oil equivalent) (about 2.5 million barrels per day) in 2030 in International Energy Agency [3].

For transportation field, Electric vehicles (EVs) used solar energy for the power charging is being encouraged as a green product replacement to traditional fossil fuel source. EVs have been proposed to mitigate the effect of climate change [4]. EVs have main types following: Hybrid electric vehicles (HEVs), Plug-in hybrid electric vehicles (PHEVs), Fuel-cell electric vehicles, Extended-range electric vehicles (ER-EVs) and Battery electric vehicles (BEVs) [5, 6, 7].

Renewable sources (RS) such as solar or wind energy will be one of the suitable options to generate power charging for electric vehicles. However, these RS are intermittent in nature and their forecast is quite unpredictable. When these RS are connected to a grid system with a large capacity, they could lead to the local power grid drops and thus an inefficiency and unreliability of the power system [8]. On the other hand, the charging and discharging process of EVs is imposed on challenges for the power grid system. These challenges compel the adjustment on the planning, operation and control of the electric grid [9, 10]. Therefore, the smart control strategies are used to charge power to EVs by the RS.

Because of the development of EVs, the charging infrastructure for EVs is very important to ensure the ability to finish the round trip and come back home. A scarcity of charging stations decreases the growth and convenience of EVs. It leads to fewer people using electric vehicles. Beyond the physical existence of charging stations, several requirements needs must be met such as the grid capacity, the convenient location for many vehicles and the charging possible technology. In other words, the power charging for EVs was divided into 50–80% of all at home, 15-25% at work, and 10% at the remaining places as supermarket, park [11]. The current charging systems for EVs include DBT [12, 13, 14]. These EV charging networks focus on providing EV chargers with the ability to identify users and take payments for public charging [15].

This research will approach different aspects of the EV via online scientific databases such as journals, information and announcement of companies to provide a general overview about it. The paper is elaborated into 5 followed main sections: In the second section, electric vehicle technology is presented. In the third section, EVs charging technology is exhibited. The fourth section is the solar power charging method for EVs. The fifth section is the economic, environment and challenging aspects, and the final is conclusions.

II. Electric vehicle technology

2.1. Hybrid electric vehicles

Hybrid electric vehicles (HEVs) are operated by an internal combustion engine in combination with one or more electric motors for traction as shown in Figure 1. The advantages of HEVs are fuel economy, efficiency, and reduced emissions. The parameters of the hybrid levels of HEVs are seen in Table 1.

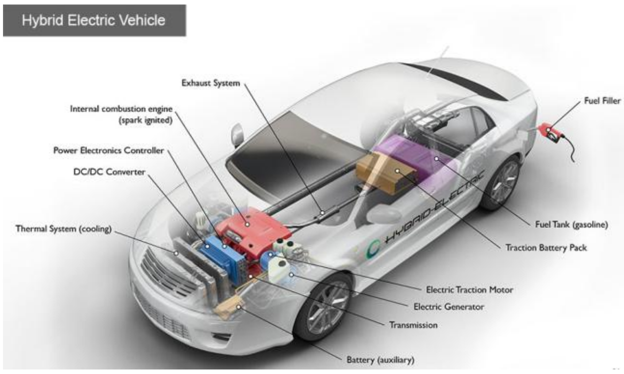

Fig. 1. Main components of a Hybrid Electric Vehicle

HEVs can not charge the battery from sources of an electricity grid system. They use regenerative braking and the internal combustion engine to charge the battery. HEVs use the electric motor as a generator to capture energy normally wasted during braking and storing the captured energy in the battery [16]. Bands manufactured HEVs such as BMW efficient dynamics, Volkswagen blue motion technologies, FIAT PUR-O2, Volvo Drive, Toyota optimal drive [17].

Table 1 . Hybrid levels of HEVs in market

Hybrids	**Micro Hybrids**		**Mild Hybrids**	**Full Hybrids**
	ISG, Stop/Start	ISG Hybrid		
Engine	Conventional	Conventional	Downsized	Downsized
Electric Motor	Belt Drive	Belt/CrankShaft	Belt/CrankShaft	CrankShaft
Electric Power	2 - 5 kw	3 - 10 kw	10 - 20 kw	15 - 100 kw
Operating Voltage	12 V	12 - 42V	60 - 200 V	200 - 600 V

2.2 Plug-in hybrid electric vehicles

Plug-in hybrid electric vehicles (PHEVs) have an internal combustion engine and electric motor. They are operated by an gasoline fuel or a electricity source. A battery of PHEV is charged electricity from electrical gric by an electrical outlet.

The electricity amount stored in the battery of a PHEV can significantly reduce petroleum consumption under normal driving conditions. They have an internal combustion and a electrical engine to charge the battery [4]. The PHEV has a larger battery-pack compared with the HEV and the PHEV can be charged from the power grid or charging station. The constituent parts of a plug-in hybrid electric vehicle are displayed in Figure 2. Bands manufactured PHEVs such as Toyota Prius Plug-in, General motors E-Flex system, MP3 Hybrid [17].

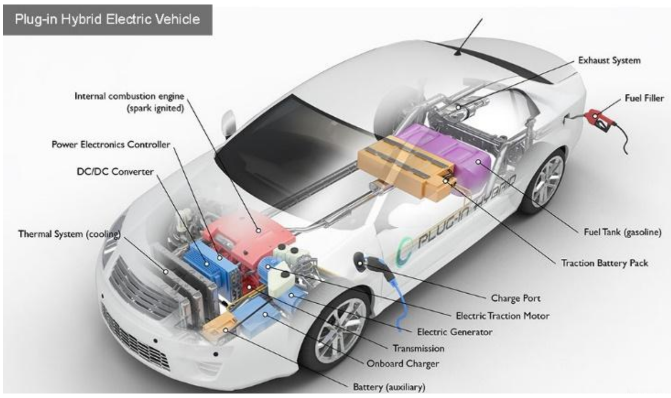

Fig. 2. Main components of a Plug-in Hybrid Electric Vehicle

There are two types of PHEV:

- PHEVs: The electrical engine rotates the wheels, and the internal combustion motor generates power to charge the battery. PHEVs can operate only by electricity motor when the battery has enough power. The internal combustion motor generates electricity to supply for the electrical engine. Therefore, they do not use gasoline for shorter trips.
- Parallel or Blended PHEVs: The internal combustion and electrical motors control the wheels. The electrical engine usually operates only at low speeds.

2.3 Fuel-cell electric vehicles

Fuel-cell electric vehicles (FCEVs) supply the electricity for an electric motor. In contrast to other electric vehicles, FCEVs generate electricity from hydrogen and oxygen, replace using electricity from the battery. They are more efficient than conventional internal combustion engine vehicles and produce no tailpipe emissions, they only emit water vapor and warm air. Bands manufactured FCEVs such as Honda FCX Clarity, Mercedes-Benz, Nissan X-Trail [17].

During the FCEV design process, the manufacturer calculates the power amount of the vehicle by the size of the electric motor that receives electric power from the sized fuel cell and battery combination. FCEV can be designed to connect the charge station for charging the battery. For FCEVs today, The electric motor converts the car’s kinetic energy back into electrical energy and feeds it into the back-up battery. The stored energy amount depends on the size of the hydrogen fuel tank.

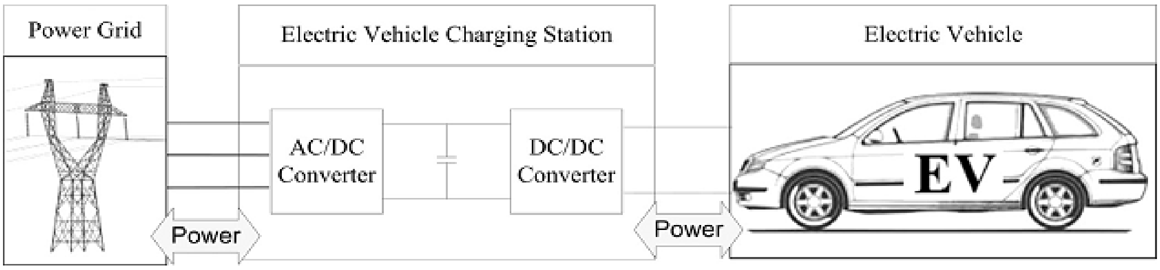

Fig. 3 Power charging diagram for EVs

2.4 Extended-range electric vehicles

Extended-range electric vehicles (EREVs) were designed to be operated by the electricity of the battery. When the power of the battery becomes low, it will be charged by a petrol or diesel generator. Electric motors have highly efficient with high power-to-weight ratios supplying suitable torque when running over a large speed range [18]. EREVs can run in the full-electric mode in the moderate distances as BEVs. For longer distances, EREVs use the internal combustion engine (ICE) to charge the battery, but consumed fuel is less than conventional ICEVs because i) The engine of an EREV is significantly smaller than an engine of an ICEV, whereas it only needs to supply an average power to charge the battery and the peak power of EREV is delivered by the battery; ii) The EREV runs at a constant rotation speed and high efficiency; An ICEV operates at low or high rotation speeds, and the efficiency is low in both situations [19].

2.5 Battery electric vehicles

Battery electric vehicles (BEVs) use fully-electric for operation by rechargeable batteries and no internal combustion engine. They are utilized for off-road vehicles such as tugs, tractors and golf carts in the

short distance. They also have been employed for a long time, but these electric cars on long-distance use have never obtained great success because of their capital cost, and time-to-recharge limitations [19].
Battery electric vehicles are charged by electricity from a charging station or an electrical outlet. BEVs do not emit any harmful emissions caused by the internal combustion engine. Bands manufactured BEVs such as Tesla Model 3, BMW i3, Ford Focus Electric [17]. Powertrain technologies of Evs are shown in [20]. EVs include ICE, HEV, REEV, BEV, and FCEV

III. EVs charging technology

3.1 Charging standards

Today, the development of EVs in the world increases quickly. Therefore, charging infrastructures is necessary for areas where EVs are used widely. The charging of EV's battery from the power grid is controlled and managed to achieve the desired benefits as in Figure 3. The aims of the charging management of EVs are to maximize profit such as reduce emissions, improve the power quality of the grid, charging system, charging cost, time, location, and the number of EVs that are charged from the power grid. There are two main charging systems of EVs: the ac and dc types, as exhibited in Table 2 [21].

Table 2. The charging standards for EVs

No.	Level	Level Max power rating (kW)	Max ampere rating (A)
I	**IEC Standard**		
AC Charging	AC Level 1	4−7.5	16
	AC Level 2	8−15	32
	AC Level 3	60−120	250
DC Charging	DC Fast Charging	100−200	400
II	**SAE Standard**		
AC Charging	AC Level 1	2	16
	AC Level 2	20	80
	AC Level 3	Above 20	-
DC Charging	DC Level 1	40	80
	DC Level 2	90	200
	DC Level 3	240	400
III	**CHAdeMO**		
	DC Fast Charging	62.5	125

3.1.1 IEC standards

AC charging system of EVs means that it converts the AC circuit to DC electric current to charge the batteries. For the AC Power Charging Levels, they are classified as:
- AC Level 1: the voltage is 120 VAC with 1-phase, an electric current is from 12 A to 16 A. This level is not a requirement to the other device and can be used to charge overnight with the standard voltage of 110 V from household's outlets. The standard connectors are NEMA 5–15, SAEJ1772 [22].
- AC Level 2: the charging voltage is 240 VAC with 1-phase, the electric current is up to 60 A. Because of the high voltage, this level needs a piece of extra equipment for power charging of EVs at household or communal charging station. The households used the voltage of 220 VAC, the connection between the EVs and the power grid is standardized and the charging time is fast [23]. The standard connectors are IEC 62196, IEC 60309, and IEC 62198-2-Mennekes.
- AC Level 3: the charging voltage is 400 VAC with 3-phase, the electric current is from 32 A to 63 A. The EV owners preferred this charging method because the charging time is fast around 30 minutes.
- DC fast charging: the electric current is from 400 A, and power rating is from 100 kW to 200kW. The charging time of the DC charger is faster than the AC charger. Therefore, It will be installed widely at commercial charging stations and places where have EVs.

3.1.2 SAE standards

The AC charging system of the SAE standards is the same IEC standards. However, the DC charging system of the SAE standards is different from the IEC one. It is divided into into 3 levels and the DC output voltage can change to suit various EVs and batteries.
- Level 1: The electric current 80 A and the rated power capacity is 40 kW.
- Level 2: The electric current 200 A and the rated power capacity is 90 kW.
- Level 3: The electric current 400 A and the rated power capacity is 240 kW.

3.1.3 CHAdeMO standards

This standard was made by the Tokyo Electric Power Company (TEPCO), it is a reliable solution to quickly charge for the EVs in the transport sector [24]. The electric current 400 A and the rated power capacity is 240 kW.

3.2 Charging control technology

EVs are charged by various operational modes such as vehicle to grid mode (V2G), vehicle to building mode (V2B) [25], and vehicle to vehicle mode (V2V) found [26].

For the V2B mode, the battery of the EVs is charged the electricity from the building power network. It means that the EV battery can be backup energy and stored energy after a trip. The charging power source is provided by the power grid system or the building renewable energy sources [27]. In the V2V mode, the batteries of the different EVs can charge or discharge among them. This mode supplies a profit to parking lot operators because they will try to maximize the profit by purchasing energy from distributed resources with the lower price [28]. The V2G mode can be divided into unidirectional and bidirectional found [29]. For unidirectional V2G, the power charging mode of each EV is controlled by the electricity grid operator to manage and prevent grid overloading, system instability and voltage drop issues [30]. The bidirectional V2G solution considers charging and discharging of EV to the electricity grid system. In another way, the EV battery can store energy and support the power grid. This solution is more advantageous than the unidirectional mode such as the sustainability of the power grid [31]. From the above knowledge, the charging control technology for EVs is presented as in Table 3.

Table 3. Charging control technology for EVs

No	Charging control Method	Algorithms
1	Central charging control	- Battery energy storage stations and automatic generation control - Multi-objective optimization - Horizon linear optimization - DC-equivalent
2	Hierarchied charging control	- Multi-agent control - Price-based demand - Game theory to control the charging process - Fuzzy logic controllers - Probability criteria (node voltage and SOC) - Autonomous charging control
3	Real time and stochastic control	- Probabilistic methods - Stochastic optimization - Robust optimization - Binary particle swarm optimization - Hierarchical optimization - Bi-layer optimization - Real-time charging management

3.2.1 Central charging control method

The charging control technology of EVs is performed when there are many data such as the current status of EVs, system information of the power grid network, number of EVs. This method is called the central charging control management. The coordination must close between the status of EVs, the charging station infrastructure, load profiles and the power network operator. Researchers and authors applied a different algorithm to connect and manage the charging of EVs from the power grid.

Zhong indicated the combination of EVs, Battery energy storage stations and automatic generation control with the power grid [32]. EVs and battery energy storage stations only respond quickly in short periods and the automatic generation control adapt in longer periods. For the PHEVs, Moeini represented a multi-objective optimization method to reduce the technical constraints when connected with the power network [33]. The horizon linear optimization method was exhibited [34], it estimated the limitation of the transformer and line, phase unbalance and voltage in the power grid system. The DC-equivalent model was used to the fact power grid system. This method was applied when the basic conditions changes suddenly.

3.2.2 Hierarchied charging control method

The hierarchy control method was used to reduce the charging station infrastructure, calculation amount, and operator's job. Specifically, the charge and discharge process is not performed by the decision of the operator, but EVs will obey commands which are installed by an operator [35]. A multi-agent control algorithm including two or more intelligent virtual or physical objectives, they depend on environmental objectives [36].

Another approach, the hierarchy control method is considered following the price to benefit between EVs and their utility. A price-based demand method used cost or primal-dual factor to suit the load change in the power grid system [37]. Researchers presented the game theory to control the charging process with the lowest generation cost [38]. In addition, fuzzy logic controllers were used to controlling the charging/discharging process of EVs to the power grid for the voltage compensation and load flattening [39, 40]. Other control algorithms, based on probability criteria (the node voltage and the state of charge (SOC)) to select EVs for charging or not. This control method performed the charging process with a maximum penetration level of 25% [41].

Besides, the autonomous charging control method is used in many countries where the communication infrastructure lacks. This controller can connect the large EV number together and depend on internal inputs to calculate the charging/discharging rate [42].

3.2.3 Real time and stochastic control method

The controller treats the signal of EV's status from 2 to 6 seconds, so this algorithm must be calculated exactly. Several difficult issues for control are market, the status of EVs and renewable energy [43]. The operator of the charging station will supply the operation schedules and capacity amount to a person who sells energy. There are some algorithms to increase the trust in this method such as probabilistic methods, stochastic optimization, robust optimization, and fuzzy optimization [44, 45, 46].

Specifically, a binary particle swarm optimization method is used to reduce the electric generating costs from fossil energy sources, and increase supplying power from renewable energy sources [47]. A hierarchical optimization algorithm is applied to suit the transformer constraints and maximum benefits for the EVs by the probability distribution method [48]. A bi-layer optimization method presented the combination the renewable energy to the power grid for the charging of EVs [49]. In addition, the real-time charging management method also was indicated [50]. Esfahani presented an adaptive real-time scheduling method to solve the congestions of the smart power grid and control the thermal level of transmission lines [51]. Moreover, the internet of things and cloud computing are applied to connect multiple aspects and technologies under different conditions [52]. The smart real-time coordination system supplies robustness, remove risk load, and quick computation time for the smart power grid system.

From the above general overviews of the charging technologies, level, and EV types, power charging areas for EVs have to select carefully:

- For residential areas: the power charging can use AC level 1 or AC level 2 chargers at condominiums, multi-family homes, and single-family homes. Level 1 chargers will suitable for private houses. AC level 2 chargers are installed in condominiums or valet service areas.
- For office buildings: level 1 or level 2 (and AC level 3) chargers are also used suggestions because employees have to work for 8-9 hours per day.
- For commercial areas: level 2 (and AC level 3) and DC chargers are used in commercial parking areas because the time dwells for buying matches with the charging time. DC chargers should be installed in publicly parking areas such as grocery stores, pharmacies, convenience stores, and on-street parking.

IV. Solar power charging method for EVs

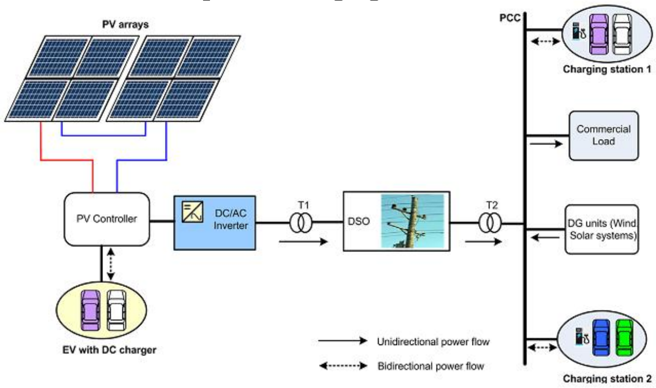

Fig. 4. Diagram of the EV charging station used PV

Solar panels (poly or monocrystalline technology) convert the light of the sun into electricity. The solar power charging method is divided into a grid-connected system and a standalone system like in Figure 4. For the grid-connected system, when solar irradiance is not enough to generate power for charging EVs, the electricity from the grid will be added for this charging process. When the solar irradiance is too much, the redundancy power will be load into the grid. It is a large advantage of this method. For the standalone system, it is convenient for remote areas or lacked infrastructure.

4.1 Grid connected charging method

The components of the grid-connected charging system are solar panels, inverters, and system loads. The solar panels can install on the rooftop of the house, parking, and connect with the grid power system. They produce DC and loaded the power grid through inverters. The voltage and frequency of the grid are used as input signals of inverter operation. If the grid gets out, inverters will not operate. Renewable energy was encouraged for generating power, so grid-connected charging stations will be developed in the future. Besides, second-life lithium-ion batteries were studied to respond to an energy buffer and provide emergency when the power grid does not supply [53].

4.2 Standalone charging method

The components of the standalone charging system include solar panels, batteries, charge controller, inverter, and the system load. Solar panels were installed in remote areas for supplying the residential/commercial charging stations without connection to the power grid. Batteries were used to guarantee the continuous power supply when solar radiation is not enough strong. On another way, the standalone charging station is a micro-grid system to feed the load (EVs) during the daytime without a battery bank [54].

4.3 Other charging method

DC Fast Charging method: A bidirectional EV charging controller was proposed to charging DC from solar panels to EV's battery. It is set between the high-voltage DC bus of solar panels and the EV's battery [55]. DC is generated by solar panels or the power grid via an inverter (AC/DC). The fast charging rate from the power output of the solar panels to the battery is diverted by the charging controller itself.

Hybrid charging method: EVs can charge from more than one power source such as the power grid, solar or wind energy. This method used backup batteries to charge EVs when the power grid lose. Solar and wind energy potential areas are good, the hybrid system (solar+wind energy) can see advantage compared with only solar or wind hybrid system because it can charge during all day because the solar panels are used in the daytime and the wind energy is used in the night-time [56].

Vehicle-Integrated PV method: EVs' body is embedded with the solar cells at hood, roof or trunk to generate the power. These vehicles become small solar power plants and more environmentally friendly. EVs can charge the power to the batteries both vehicle standstill and operation. Hence, It will supply the power for equipment on the EVs such as air conditioner, heating, displays, etc [57]. In addition, the thin-film photovoltaic technology was considered to paste on the EV's body.

V. Economic, environment and challenge aspects

5.1 Economic aspect

For the EV owners, the saved cost from the EV operation is important. Besides, the costs of EV manufacture are reducing in the future because of mass production and better energy policies. Another benefit of the EV is the finance amount from selling the electricity to the grid manager. Moreover, the price of the solar power system also is decreasing in recent years. Therefore, the EV charging technology used in the solar power system will develop strongly. Various studies were discussed the economic benefits of EV charging from solar panels. For example, the Northeast Asia area has a huge amount of renewable energy potential, and its share increases from 20% to 47% in the base case, this led to the CO_2 emission reduction of 36% [58]. The renewable energy sources help the EV owners saving fuel costs, but they have to invest in the solar power system and other extra costs.

5.2 Environment aspect

Because internal combustion engine vehicles burn fuels directly and emit carbon dioxide and carbon monoxide, so EVs were developed to overcome the ICEV's disadvantage. In addition, if renewable sources are used widely, the emission amount from generating the power and transportation sector will be reduced. For the EV power charging station, if this system consumed electricity from traditional power generated plants, it leads to increasing the greenhouse gas emission amount. However, for EV development, the charging station uses the power from renewable energy sources, it will improve the increasing greenhouse gas emission.

Many countries in the world have signed the Paris Agreement in 2015 with the common aim is to overcome global warming and environmental pollution reduction. Hence, these countries developed renewable energy projects with a large capacity to respond to increasing consumer demand. Specifically, the installed capacity of solar power projects has obtained over 586 GW, and wind power projects of 622 GW on the worldwide in 2019 [59].

5.3 Challenges for the EVs development

EV development has many advantages and environmental benefits, but it still remains the challenges and barriers to the sustainable growth of EVs:

Battery limitation: Cells of the battery will decline gradually after the charging or discharging process. It means that the battery useable capacity is decreased [60]. The battery aging is longer, the charging/discharging process, voltage, and temperature have to control. However, the fast charging/discharging process leads to the battery cell's ugliness. In order to predict the battery life, an equivalent series resistance parameter is used to estimate. When the charging/discharging process is performed and extreme depth, the equivalent series resistance parameter will increase under low battery temperature and extreme battery State of Charge (SOC) [61].

High investment cost: the initial investment cost of the solar power charging station is high for hardware and software infrastructure. EVs connect with the power grid system by bidirectional battery charger system. Besides, the charging/discharging process for EVs has energy loss, it means that financial benefit reduces.

VI. Conclusion

This paper reviews the EV types, the charging technologies, the solar charging system, and other aspects related to EVs. The development of solar power and EV sectors will decrease CO_2 emissions and fossil fuel consumption. The solar power system only operates in the daytime, so it is a restriction of this system. EVs have clean, efficient, and noise-free compared with internal combustion engines. EVs are connected with the smart power grid system for charging the battery and the grid support. This method can combine renewable energy sources to decrease fossil energy consumption. Real-time communication is an advanced and complex technology that estimated the challenges and limitations for the charging EVs such as communication delays, routing protocols, and cybersecurity. To the EVs operates effectively, the charging/discharging process of the battery must be controlled, because the charging/discharging frequency is performed continuously. Besides, the solar power charging station infrastructure need to select strategic locates favorable for EVs charging. The fast charger needs to develop for the benefits of the users because it will reduce the charging time. There are various developed potentials for the EVs industry section, for example, there are different algorithms for utility in the EVs such as deterministic, fuzzy logic, and optimization genetic algorithms. Therefore, the studies of EVs should provide interesting topics for future research.

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