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The Effects of EV on Electricity Billing Structures and Electricity Rates on Solar Photovoltaic Project

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Electric Vehicles are gaining a foothold in the global auto market as a sustainable transport solution, which would allow reductions in greenhouse gas emissions and less reliance on fossil fuels. Their incorporation into the power grid facilitates some opportunities and challenges, especially with electricity demand, pricing structures, and charging facilities. At the same time, the advent of solar PV systems allows for the provision of less carbon-intensive alternatives for the demand of charge to EVs and in improving grid efficiency. However, several challenges to widespread EV uptake still exist, including short driving ranges, charging infrastructure problems, high upfront costs, and battery degradation. This study does consider the interaction between EVs and solar PV as it pertains to electricity markets, billing schemes, and long-term energy sustainability. Smart charging systems and V2G integration provide further promise to balance supply and demand while always maximizing the use of renewable energy. Technology advancements of batteries, greater infrastructure extension, and policy incentives can prove crucial in promoting EV adoption. Together with the world embarking on a transition toward cleaner modes of transport, the tandem working of the two technologies-BeVs and solar PV-provides a strong impetus toward a sustainable and energy-efficient.

Keywords: Electric Vehicles, Plug-in hybrid electric vehicles (PHEV), plug-in electric vehicles (PEV), greenhouse gas (GHG), photovoltaic (PV).

1. Introduction

Although the concept of electric vehicles (EVs) was initially proposed in the late 1830s, it was unable to compete with the rapidly changing fossil fuel-powered automotive sector. They are powered by electricity that is directly taken from the grid through any authorized electric power channel, such as at home, at work, or at any parking lot. Therefore, once EVs and the grid are connected more closely, it will cause issues for the outdated power systems. On the system, plug-in electric vehicles (PEV) and plug-in hybrid electric vehicles (PHEV) have begun to proliferate. Concerns have also been raised about the advantages and effects of electric vehicles as technology advances and consumer adoption rises. Researchers are very interested in the services that EVs may offer to the current power system, and this topic is quickly gaining popularity [1]. There are numerous reasons why electric cars (EVs) are becoming more and more popular. Their role in lowering greenhouse gas (GHG) emissions is the most notable. In 2009, 25% of the greenhouse gas emissions from energy-related industries were from the transportation sector. It is anticipated that EVs will lower that number once they become sufficiently prevalent in the transportation industry, but this is not the only factor reviving this century-old and once-dead idea as a product that is both commercially feasible and accessible [2].

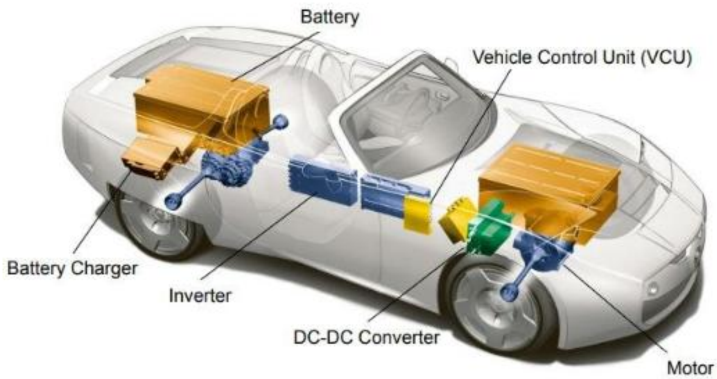

Fig.1 Electric vehicle (EV) Dynamic modelling [8]

The electrical industry has long hailed solar photovoltaic (PV) power as an energy source with vast promise. Growth rates for new installations have been continuously high, especially within the last 10 years, as the yearly installation capacity has increased annually. In 2017, the 300 GW of existing capacity was augmented by an additional 100 GW of new capacity installations worldwide. Currently, 6.3% of installed capacity and 1.7% of electricity generation worldwide come from solar power. The cost of solar systems dropped sharply in recent years as solar PV deployments increased quickly. As you can see, by late 2017, the average sales price of PV modules has dropped from over $4 per watt in 2007 to about $0.35 per watt [3].

2. EV Charging System

EV charging has its major consequence for the wholesale electricity market, which underlines the importance of highlighting charging behaviour. Psychological factors that would invoke target behaviour in EV operators have been discussed in different studies. Charging transaction data and interviews with EV drivers have provided some pivotal insights into selection parameters impacting charging behaviour. Such studies give a certain overview. But, in order to reap the maximum benefit, quantification of these studies is necessary for a relevant scheduling and management approach [5]. In this regard, some analyses lean towards simulation to study EV charging behaviour. However, these simulations often rely on assumed and generalized conditions, which may not be applicable under real conditions. Similarly, estimating EV charging behaviour based on ICE vehicle-driving data or generated synthetic data may not account for the unpredictable nature of everyday EV charging.

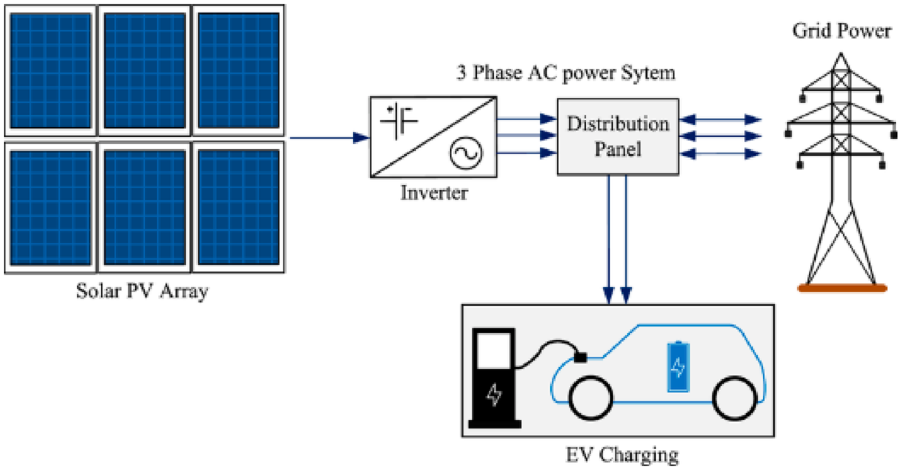

Fig.2 EV charging system with Solar power system [4]

Solar photovoltaics (PV) and electric vehicles (EVs) are two extremely promising new technologies that are anticipated to have a significant impact on the electricity sector over the next ten years. Concerns about future oil prices and availability, together with growing concerns about climate change, are driving the adoption of electric vehicles (EVs), which have the potential to form a major part of the fleet of transport vehicles in the future. Due to its potential to help address environmental issues and the security of the electrical supply, solar photovoltaics (PV) has been one of the renewable technologies with the quickest rate of growth in the globe over the last 10 years. Given its declining costs, PV deployment is expected to continue expanding quickly [6].

- The Impact of EVs Charging

Using a long-term generation and transmission expansion co-optimization model, the effects of widespread car electrification on power system expansion planning are examined. Both private and public EV demand are taken into account in the suggested model, which is applied to the system's hourly operation. The model can better use the unique characteristics of the resulting generating portfolio thanks to intelligent charge schemes. Among other things, the benefits are examined in terms of total costs, marginal costs, and emission levels. Inputs included historical hourly capacity factors of various RES power plants, demand predictions for each power bus, and actual vehicle travel patterns in Chilean cities. Using data from a year of actual operations and clustering algorithms, representative days were used to communicate the majority of these parameters into the model [7].

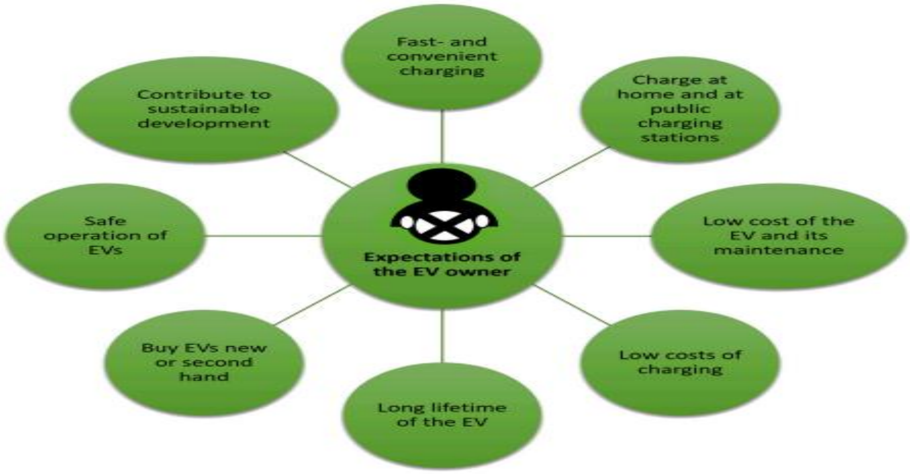

Fig. 3 overview of EV on e.g. the vehicle and the access to charging infrastructure [14]

3. Different EV Types

EVs can be powered exclusively by electricity or in conjunction with an internal combustion engine. Although some EVs can use alternative energy source modes, the most basic type uses simply batteries as its energy source. One term for this is hybrid electric vehicles (HEVs). According to the International Electrotechnical Commission's Technical Committee 69 (Electric Road Vehicles), a car can be classified as a hybrid electric vehicle (HEV) if it has at least one electrical energy source, storage device, or converter. ICE and battery, battery and flywheel, battery and capacitor, battery and fuel cell, and many other combinations are made available by this description for HEVs. Consequently, both the general public and experts began referring to cars with an ICE and electric motor combination as HEVs, cars with a battery and capacitor as ultra-capacitor-assisted EVs, and cars with a battery and fuel cell as HEVs. Since these terms have gained widespread acceptance, EVs can be grouped in the following ways [10]

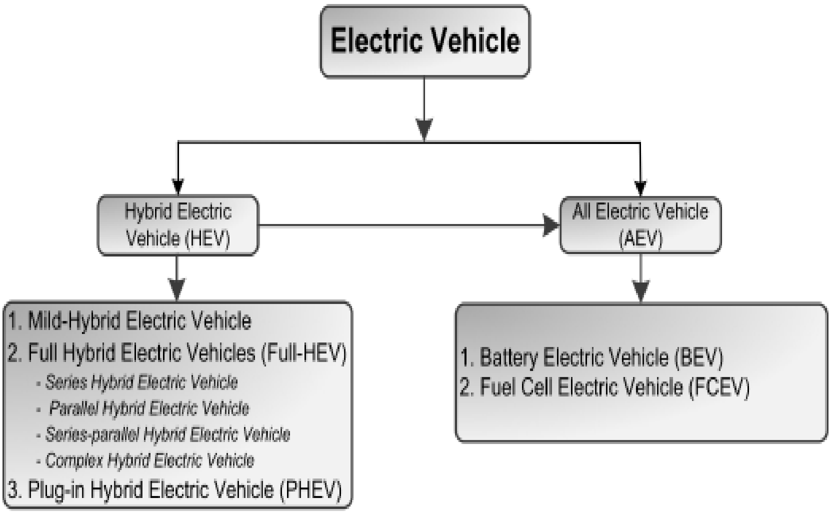

Fig. 4 The classification of EV [9]

- Hybrid Electric Vehicles: Like EVs, HEVs are able to recuperate the kinetic energy of the braking vehicle. In contrast to an EV or an ICE car, the HEV powertrain is more complicated. Its controls and components are the source of its intricacy. This page provides a summary of the key parts used in the HEV powertrain, including their architectures, hybrid energy storage systems (HESSs), traction motors, power electronic converter selection, and energy management methods (EMSs) [11].

A. HEVs has some basic types

- Mild- Hybrid Electric Vehicles: Due to the little adjustments and financial outlay required to adapt the conventional vehicle, mild hybrid electric vehicles are present in a number of commercial vehicles. A little electric motor is incorporated with this hybrid technology to help the ICE in high load, idle, and start-stop situations. Additionally, a portion of the braking energy can be converted into electric energy by this little electric motor, which can also function as an electrical generator. Furthermore, because of the electric motor's low power rating, it does not require a high-power energy storage system. The needs might be satisfied using a 48 V electrical system. The FHEV is even more complicated, with a larger electric motor, a more sophisticated control system, and a battery package. Depending on how the ICE is connected to the vehicle's wheels, FHEV can be divided into three distinct architectures: Parallel, Series, and Series-Parallel [12].

- Full- Hybrid Electric Vehicles: Compared to conventional automobiles, full hybrid electric vehicles (FHEVs) and hybrid electrical vehicles (HEVs) have a greater number of electric components. Power trains are really made up of electrical machinery, power electronics, and electric energy storage devices (such as batteries and super capacitors) that are connected to mechanical parts (such as gearboxes, wheels, and transmissions) and, in the case of a hybrid electric vehicle (HEV), to an internal combustion engine (ICE). In order to consider the dynamic interplay between all of the vehicle's components and the power train itself, a modern vehicle design must use a multidisciplinary approach. Since prototype and testing are costly and intricate processes, the vehicle designers require modelling and simulation to determine the proper component sizing, the optimal energy control technique, and to limit the vehicle's energy consumption. It can be difficult to create a simulation model that is accurate enough for all the many components depending on the several physic domains (electric, mechanical, thermal, power electronic, electrochemical, and control). The automobile designer uses a variety of commercial simulation tools that have been proposed in the literature [13].

- Plug-in Hybrid Electric Vehicles: When powered by electricity, plug-in hybrid electric vehicles (PHEVs), which combine an internal combustion engine and an electric motor, have the potential to lower greenhouse gas emissions (GHG) and help meet the goals set forth in the Paris Agreement. However, PHEVs' real-world fuel consumption (FC), which is based on actual driving behaviour and the percentage of kilometres travelled on electricity, or the so-called utility factor (UF), greatly influences their ability to lower local pollutants and global GHG emissions. These test cycle values are typically taken into account for calculating PHEVs' CO2 emissions. However, the UFs utilized in the WLTP and NEDC test procedures may overstate UFs and underestimate the actual FC and, consequently, emissions of PHEVs because they are based on out-of-date data that was mostly supplied by vehicle manufacturers [15].

- Battery Electric Vehicle: An electric vehicle (EV) that runs only on compound energy stored in rechargeable battery packs without the need of any other sources (such as an internal combustion engine, hydrogen energy component, etc.) is known as a battery electric vehicle (BEV). BEVs are propelled by an electric engine and system rather than an internal combustion engine (ICE). Battery packs provide them with all the force they need to drive the engine, which helps move the wheels. Other names for them include all-electric automobiles, pure electric vehicles, and unadulterated electric vehicles. Cruisers, bikes, skateboards, railcars, watercraft, forklifts, transports, trucks, and other vehicles are all included in the category of battery electric vehicles, or BEVs. A single speed transmission, an electric engine with a power electronics controller, and a high-voltage battery make up the battery electric vehicle's engineering. Since battery electric vehicles are the most practical path to an ideal and efficient vehicle framework, their share of the industry is growing. The main advantages of a BEV over ICE vehicles are its overall high effectiveness, durability, and relatively little effort required by the electric engine [17].

- Fuel cell Electric Vehicle: Fuel cell electric vehicles and other vehicles will be necessary to significantly reduce our reliance on foreign oil and the carbon footprint of the transportation sector. Butanol, ethanol, and biodiesel are examples of biofuels that show promise, particularly when derived from cellulosic feedstocks. Although natural gas can lower greenhouse gas emissions and oil consumption, it is only a short-term transition fuel. Electricity and hydrogen may someday replace fossil fuels as our main sources of carbon-free transportation. Hybrid electric vehicles (HEVs) that run on gasoline are already having a minor effect on the fleet of light-duty vehicles, and plug-in hybrid electric vehicles (PHEVs), which get some of their energy from charging batteries from the electrical grid, might soon be available for purchase. In addition to lowering oil use, the combination of biofuels with PHEV may also significantly lower greenhouse gas emissions, depending on the fuels used at power plants in each region to generate electricity. In the end, all-electric cars that run on batteries or fuel cells may significantly help us reach our long-term social objectives [18].

B. Key components of EVs

Electric vehicles (EVs) are built around several hardware components that will directly determine their efficiency, performance, and overall functionality. They include but are not limited to traction batteries, electric drive motors, and power electronics. Continuous research into the integration of these components will enable the advancement of next-generation EVs. Traction batteries are key components of propulsion systems for EVs, providing energy to power the vehicle. Modern hybrid electric vehicles (HEVs) utilize either nickel-metal hydride (NiMH) or lithium-ion (LIB) batteries. Owing to their superior energy density and long life, LIBs are more frequently replacing NiMH battery systems, though NiMH continues to play a relevant role in some HEV designs. Creating efficient and sustainable battery technology continues to be the objective of extensive research directed towards improving the performance and range of EVs.

The electric drive motor converts electrical energy to mechanical energy in order to propel the vehicle. There are different types of motors based on application, powertrain, configurations, and efficiency requirements. Power electronics are the other critical component of the control system that regulates the flow of energy between the battery and the motor. They include many sub-components that are pivotal in their own right, for instance, inverters, DC voltage converters, other DC converters, and on-board chargers, to improve the overall energy efficiency of the EV drive train.

4. Demand Charges and Their Role in EV Electricity Costs

A rapid increase in electricity demand is regarded as one of the most serious problems that face power. Though most EV charging occurs at private residences when cars are parked overnight, DCFC stations are intended to (a) offer a charging opportunity for those who might not have reliable access to home or workplace charging infrastructures; (b) facilitate long trips, therefore addressing range anxiety issues while providing mobility service to EV drivers comparable to that given by conventional gasoline vehicles. Stations of this sort typically provide several 50 to 120 kW plugs. Their primary purpose is to provide battery electric vehicles with an opportunity for fast travel or for opportunity charging in transit through urban areas (taking advantage of a stop to recharge a vehicle while it still has battery capacity left) [20].

The electricity pricing mechanism is a stimulator and guide for customer electricity demand and consumption mode. Customers would react to price changes in electricity with variable prices, choosing between charging and discharging and actively altering the charging rate and time. Research has concentrated on this area for countries with a mature electricity market environment. For instance, introduces an EV charging model based on price information in real-time, while optimizing the charging process, using quadratic programming that considers the relationship between electricity price and load demand. The objective is to minimize charging cost and maximize discharging profit. Reference uses linear programming model to respond to the real-price [21].

Table1. Comprehensive Analysis of Solar PV Systems, Electric Vehicle Integration, and Economic Impacts across Various Research Studies

Reference	Topic	Objective	Methodology	Findings	Key Metrics
[27]	Solar PV for EV Charging Stations	Design a grid-connected PV system for EV charging and appliance consumption.	PVSOL Simulation	PV meets 66% EV charging demand, reduces 5 tons CO2/year; payback period ~5 years.	Yield: 1,786.69 kWh/kWp, Cost: $0.0032/kWh, Savings: 21%.
[28]	Tariff Impact of PV and EV Adoption	Analyse tariff changes for household groups with PV, EV, or both.	Tariff Analysis	PV raises tariffs for all; EV reduces tariffs across all customer groups.	Tariff trends for London vs. Scottish networks.
[29]	Co-Adoption of EV and PV	Study behaviour and demand shifts when EV users adopt PV.	Difference-in-Differences	Grid demand drops 1.1 kWh; annual consumer savings ~$930; peak load reduction.	Charging shifts to daytime, co-adoption savings estimated ~$925.
[30]	LCOE for Solar PV	Improve LCOE clarity and assumptions for better reporting and decisions.	Methodology Review	Grid parity achieved under favourable terms; template provided for standardized LCOE reporting.	Sensitivity to financing terms and grid price comparisons.
[31]	Time-Varying Pricing for EV Charging	Evaluate pricing impacts on EV-PV adoption and grid integration.	Agent-Based Modelling	Hourly rates improve EV-PV synergy; mitigate carbon emissions; reduce ramping needs.	80% EV midday charging, reduces retail price increase, optimizes PV use.
[32]	Spatio-Temporal PV-EV Modelling	Review combined modelling of PV production and EV charging.	Literature Review	Identifies gaps in load modelling, charging profiles, and ramp-rate accuracy.	Research priorities for city-scale modelling and spatial weak points.
[33]	PV and Energy Storage Economics	Explore profitability and sizing of PV with storage for residential use.	Economic Modelling	Storage improves self-consumption, increases PV system size, and enhances profitability.	Profitability depends on incentives, metering, and pricing models.
[34]	EV Charging Pricing Models	Develop a dynamic charge price model for EVCI-PPP projects.	System Dynamics Approach	Operating costs, charge volume, and electricity price are critical pricing determinants.	Sensitivity analysis on profitability and pricing optimization.
[35]	Hybrid PV-Battery Systems	Evaluate economic implications under ToU and TR pricing.	SAMA Simulation Tool	ToU pricing supports PV viability; battery storage remains less viable under current conditions.	Tax credit improves financial feasibility; rate structure impacts.
[36]	Community Solar in Rural Areas	Address challenges and benefits of community solar for underserved regions.	Case Study Analysis	Offers sustainability and energy independence; faces regulatory and financial barriers.	Promotes decentralized energy; solutions for equitable distribution.

5. Electricity billing Structures and Electricity rates on solar photovoltaic

The electricity meter does the billing of electricity according to amount of power utilized by the individual consumers. The prepaid meter not only automates (AMR) the reading but also allows prepaid recharging and can have information exchanged between the grid and consumer. The data of the actual power consumed and sent by the prepaid electric meter can be stored in the grid computer for later verification. The primary objective of this project is to automate the billing system for energy. The front end of the Project is user-friendly, and even an employee with very rudimentary knowledge of a computer can handle it [22].

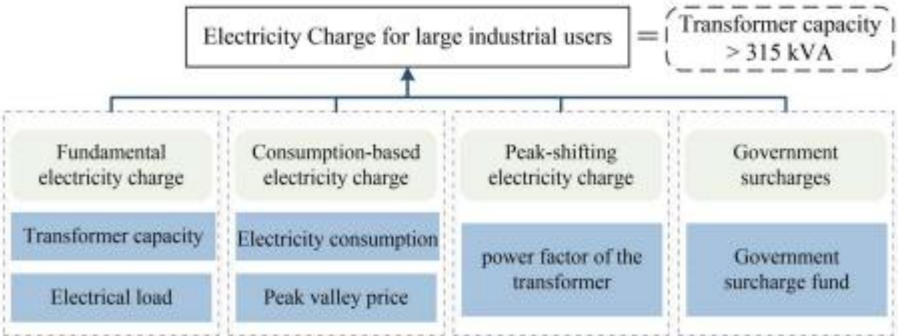

Fig.5 Composition of electricity billing charge [23].

6. Solar Photovoltaic Projects and EV Charging Synergy

However, there are still serious barriers in the market for decarbonisation of transport that need to be removed through government economic and policy support. According to analyses done by NREL and other agencies, not having regular charging infrastructure at home or other venues will make the ambitious market outlook moot. A similar situation arises where the penetration of EVs and variable renewable energy would have disruptive and costly consequences on the distribution grid. However, all passenger cars electrified cannot transform the sector into a decarbonized one unless pathways to carbon-free electrification join EV charging with the supply of clean energy. In order to maximize synergistic benefit, reduce the risks involved in integrating and scaling both solar and EV charging, and expedite their mutual deployment, the study looks at the possibility of deploying PV and EV charging infrastructure together [24]. Since the early 18th century, electric vehicles have been viewed as a viable mode of transportation. On the other hand, by the time the transportation system was electrified, electric vehicles had already become the best-selling vehicle on the road and were mostly used in public transportation (trolleybus, tramcars) and railway-based transportation. Geographical limitations resulted from the electric supply's reliance on a track-based direct connection to specialized electrical networks (either DC or AC based supply). The use of mobile computers and telecommunications devices has spurred recent advancements in power storage, leading to significant innovations in battery autonomy and portability (weight, size). EV development and discussion as a possible private or public transportation option have benefited greatly from more compact, lightweight, and efficient batteries [25].

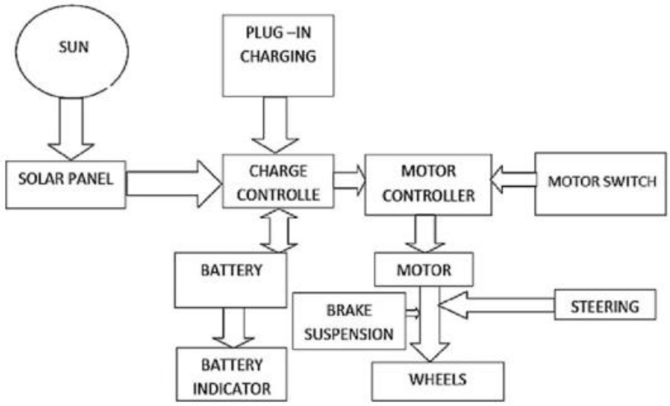

Fig. 6 Block diagram of solar charging electric vehicle [37]

Smart inverter control methods, which take into account curtailed PV energy, net power flows, voltage profiles, and renewable penetration, can effectively balance the peak EV charging loads during the daytime. Accordingly, peak load shifting, minimizing the impact of peak periods, limiting demand at a fixed level, and attempting to capture all PV generation controls may be sufficient for a single system. Moreover, curtailment rates above 10% and non-exportable solar PV penetrations above 35% can be reduced by shifting flexible loads, such as EV charging, to periods of high renewable energy generation. Using EV charging stochastics and sensitive loads on the demand side of energy management can meet economic operating targets and reduce CO2. Even rapid PV generation fluctuations at distribution network busbars can be alleviated by a variable EV charging process, but the cost of charging for EV owners increase. Integrating EV charging as a load rather than a capability to offer flexibility does not reduce operating costs enough to reduce the benefit margin [26]

7. Advantage and Disadvantage of EVs

A. Advantage

This machine's relative environmental friendliness is without a doubt its greatest advantage. It releases tons of dangerous materials and products into the sky instead of burning fuel. Additionally, owners of these vehicles can save petrol because it's uncertain when the next energy crisis will occur and gas prices will increase. One nice perk of driving will be the lack of stink and noise.

Electric vehicles are environmentally friendly and sound alternatives for fossil-fuel-powered vehicles. Since they produce no tailpipe emissions, they reduce air pollution and carbon footprint. Hence, being more sustainable, they make a better pick for the future in transportation. Key amongst the benefits of electric vehicles is their lowered cost of operation. Their few moving parts mean they require little maintenance and are long-term expense-saving because electrical energy tends to cost less than gasoline.

Electric cars are another class of energy-efficient vehicles. Their motors transmit a higher portion of energy they receive towards the wheels when compared with internal combustion or petrol/diesel engines, allowing for a much better overall efficiency. Basically, they give better performance by using less energy.

To promote the uptake of EVs, governments have instituted various incentives, tax credits, and rebates. Such financial benefits can substantially lower purchase-price barriers, making electric vehicles much more easily accessible. EVs run quietly. Unlike traditional cars, noise generation is at a minimum. This helps diminish the noise pollution within urban areas. A very serene and enjoyable driving experience is thus granted.

B. Disadvantage

The cost of these machines is quite high because these advancements are still in their infancy and are not yet ready for large production. Many cities' infrastructure is not built to accommodate electric vehicles. Furthermore, the batteries' longer than eight-hour runtime is not sufficient for a lengthy journey without charging.

One of the primary drawbacks of electric cars includes limited driving range on a single charge. This can be a very serious problem for those who travel long distances regularly because they may have to plan their routes beforehand in order to accommodate some stops for charging stations. Other issues include charging infrastructure availability. While charging stations are being set up in larger numbers, they aren't as widely available as gas stations, especially in some regions.

This makes it increasingly inconvenient and difficult for EV owners to travel long distances. They can also be a little expensive. Although the operational cost of EVs is low, they generally cost greater than their gasoline-powered counterparts. Even discounts and rebates from governments may fail to offset the price difference for some consumers. Charging an electric vehicle also takes longer than simply pulling up to a gas station and pumping gas. Sure, there are fast-charging stations, but their time and convenience hardly compare with filling up with gas. They pose a serious inconvenience for drivers who are working on deadlines. Last but not least, an electric car suffers battery degradation over a lifetime and suffers diminished range and efficiency as a result. With time, batteries will begin to antidote themselves. The cost of battery replacement may make ownership of an EV quite expensive in the long run.

8. Conclusion

Electric vehicles are quickly becoming a transformative solution for the transport sector, with enormous prospects for environmental and economic benefits. They would help reduce greenhouse gas emissions, dependence on fossil fuels, and therefore contribute to cleaner air: they can be regarded as the backbone of sustainable mobility. Besides, improved battery storage technologies, charging infrastructures, and renewable energy integration continue to improve the feasibility and adoption of electric vehicles. Challenges that will remain the cause for concern include limited range, constraints on electricity charging network, high up-front costs, and the aging of batteries among the electric vehicles. It would take the coordinated contribution of government, industry, and researchers to advance the field of battery efficiency, expand the charging networks, and develop policies that promote affordable and accessible systems. The integration of EVs with renewable energy sources, particularly solar photovoltaic, could reduce carbon emissions further as they can optimize electricity consumption. Smart charging strategies along with vehicle-to-grid technologies may enhance energy efficiency and help stabilize electricity demand and support transitioning to more resilient and sustainable energy systems. Increased adoption of EVs should galvanize research and innovation to eliminate existing barriers and maximize prospects. Infrastructure, consumer incentives, and battery evolution may remain paramount in accelerating a clean-energy future. In conclusion, electric vehicles could serve as one of the most vital steps toward reduced effects on the environment, enhanced energy security, and development of a sustainable transport system. The road ahead, no doubt, is laden with challenges; nevertheless, the continuous strides taken in technology, policy, and infrastructure development will certainly make electric vehicles a much more viable mode of transportation in the years to come.

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