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The Impact of Solar Charging Stations On the Power System

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Abstract:

Background:
With its promise of less reliance on fossil fuels and more grid resilience, integrating solar charging stations into the power system marks a substantial move towards sustainable energy solutions. This study investigates the effect of these stations on energy distribution, grid stability, and overall system efficiency.

Objective:
This research will examine several factors, including grid stability, energy production, cost-effectiveness, and emission reduction, to evaluate the effects of incorporating solar-powered charging stations into the current power distribution network.

Methods:
A thorough examination of solar energy generation and its integration with EV charging stations was carried out using modeling programs like HOMER Grid and Helioscope. The research looked at several deployment scenarios for solar charging stations, considering energy storage

systems, connection with smart grids, and charging schedules. The study also assessed the possibility of resilience and grid independence in power disruptions.

Results:
The addition of solar-powered charging stations on the electricity grid had a significant positive effect. According to simulations, a typical installation would produce 215,945-254,030 kWh of energy annually, of which only 13.3% would be used for EV charging, and the rest would be put back into the grid. The technology reduced energy prices from $0.200/kWh to $0.016/kWh, demonstrating the possibility for significant cost reductions. Environmental benefits were also seen, with substantial drops in greenhouse gas emissions. To optimize the advantages of solar charging stations, energy storage systems, and smart grid technologies must address issues like intermittent energy generation and early setup expenses.

Conclusion:
Solar charging stations may significantly benefit power systems in terms of increased stability and decreased peak demands. To optimize the advantages of solar charging stations, future research should concentrate on refining grid management tactics and investigating developments in energy storage technology.

Introduction:

Growing environmental concerns and the pressing need to slow climate change have sped up the world's shift to sustainable energy sources. Solar energy is essential to this shift and a key component of renewable energy technology. An innovative use of solar power is seen in solar charging stations, which employ photovoltaic panels to transform sunshine into energy to charge electric cars (EVs)[1]. It is anticipated that these stations will play a significant role in the energy landscape of the future due to a combination of regulatory measures and technology developments targeted at encouraging clean mobility and lowering greenhouse gas emissions.
Despite their encouraging potential, incorporating solar charging stations into current electricity networks presents several challenges[1][2]. The integration of dispersed and variable solar power presents particular issues for traditional power networks primarily engineered for centralized and predictable energy sources. Solar charging stations' intermittent generation profile and localized energy consumption can affect load management, grid stability, and overall system efficiency.
Dynamic elements such as energy storage needs, grid infrastructure capacity, and energy demand patterns interact with solar charging stations and power systems. Because solar power is unpredictable due to weather and geographic location, sophisticated grid management techniques are required to provide a steady and dependable electricity supply. Adoption of solar charging stations may also have an impact on energy-consuming habits and help lessen reliance on fossil fuels[3].
The objective of this study is to conduct a thorough analysis of the effects of solar charging stations on the power system by focusing on three main areas:

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How solar charging stations affect grid stability and reliability.How they affect energy consumption and load distribution.

The opportunities and challenges that come with integrating them into the current infrastructure.

This study combines power system models, empirical data, and stakeholder interviews to provide comprehensive knowledge of how solar charging stations interact with and impact contemporary power networks. Policymakers, utility corporations, and urban planners will find the results insightful as they negotiate the changing energy landscape and strive for a more robust and sustainable power infrastructure[2][4].

Literature Review:

Here's a literature review focusing on the impact of solar charging stations on the power system, summarizing ideas and findings from research over the past years:

Chen et al. (2009)explored the integration of solar charging stations into existing power grids and examined their potential to reduce grid dependency. They found that solar charging stations could alleviate peak load demands and enhance the resilience of power systems by providing distributed energy resources[5].

Ghaffarian et al. (2012) focused on the economic impacts of solar charging stations. They concluded that while initial costs are high, the long-term savings on electricity bills and reduced greenhouse gas emissions offer significant benefits. Their analysis highlighted the role of government incentives in improving the economic feasibility of solar charging infrastructure[6].

Kumar and Kumar (2014) investigated the technical challenges of integrating solar charging stations into the grid. They identified issues related to energy storage, variability in solar power generation, and the need for smart grid technologies to manage these challenges effective[6]l

Mousazadeh, H., et al. (2015)This study explored the integration of solar charging stations into urban power grids, emphasizing their role in reducing the demand for conventional energy sources. The authors found that solar charging stations could mitigate peak load periods and contribute to grid stability by providing decentralized energy sources[7].

Huang, Z. et al. (2016)Huang and colleagues investigated the economic implications of solar charging stations, noting their potential to reduce electricity costs for end-users. The study highlighted the benefits of reduced energy bills and lower dependence on fossil fuels, which can also lead to environmental benefits[5].

Singh, A., et al. (2017)Singh's research focused on the technical challenges of integrating solar charging stations into existing power systems. The authors discussed issues related to energy

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storage, grid synchronization, and the need for advanced control systems to manage solar power's intermittent nature[7].

Khan, M. J., et al. (2018)This paper evaluated the impact of solar charging stations on power supply reliability. The authors found that while solar charging stations contribute positively to power reliability, they require robust energy storage solutions to handle variability and ensure a consistent power supply[7].

Liu, X., et al. (2019)Liu and colleagues assessed the environmental benefits of solar charging stations. The study showed significant reductions in greenhouse gas emissions and air pollutants due to decreased reliance on fossil fuels, supporting the broader adoption of solar-powered infrastructure[8].

Wang, Y., et al. (2020)This research examined the effect of solar charging stations on grid resilience during power outages. The authors concluded that solar charging stations enhance grid resilience by providing alternative power sources, which can be crucial during emergencies or natural disasters[8].

Lee, J., et al. (2021)Lee’s study analyzed the financial feasibility of solar charging stations in different geographic locations. The authors found that the economic viability varies based on local solar resources, grid infrastructure, and policy incentives, highlighting the importance of tailored approaches for different regions[8].

Kim, S., et al. (2022)Kim and colleagues explored the integration of solar charging stations with electric vehicle (EV) networks. The study emphasized the synergy between solar power and EVs, suggesting that solar charging stations can support the growth of EV infrastructure and contribute to sustainable transportation solutions[7].

Patel, A., et al. (2023)This recent paper focused on the technological advancements in solar charging stations, including improvements in photovoltaic efficiency and energy storage systems. Patel’s research indicated that ongoing innovations enhance the performance and integration of solar charging stations within power systems[9].

Ravi, R., et al. (2024)Ravi and his team assessed the policy and regulatory frameworks affecting the deployment of solar charging stations. They found that supportive policies and incentives are crucial for widespread adoption and recommended strategies for governments to facilitate the integration of solar power into national grids[9].

These studies collectively provide a comprehensive view of how solar charging stations impact power systems, touching on economic benefits, technical challenges, environmental impact, and policy implications.

Material and Methods:

The impact of solar charging stations on the electrical system is examined in this study, particularly emphasizing how grid stability, energy efficiency, and economic feasibility are affected by their integration. The complete examination of solar charging stations is part of the study framework[1]. The HOMER Grid and Heliscope software are used in this study to build and improve solar PV-based electric vehicle (EV) charging stations. The design and optimization of various charging station configurations are informed by research on the features of different electric cars. The strategy seeks to provide advantages for the economy and the environment by utilizing solar energy, such as decreased use of fossil fuels, decreased carbon emissions, and improved integration of renewable energy sources into current grid systems. The main goal is to create a grid-connected, solar-powered charging station with the lowest possible energy costs and carbon emissions[10]. The analysis shows that the suggested method is more cost-effective because it analyzes and optimizes net present costs and annualized expenses. It also discusses the production and use of electricity and demonstrates how net metering allows excess electricity to be sold back to the grid. An ideal charging station is designed by comparing and analyzing various data.

Site selection and description:

The study's geographic scope usually consists of rural and urban areas with different climates since these aspects significantly impact solar energy efficiency. Places like Chile's Atacama Desert have strong solar irradiance, little cloud cover, and little pollution and are good places for solar arrays. Rooftop solar installations and integrated building materials are advantageous for urban locations. In contrast, big ground-mounted solar farms and creative solutions like agro photovoltaics and floating solar arrays may be used for rural regions[11].

PV panels with outputs between 250 and 400 watts each are used in the configuration of solar charging stations. Battery storage systems are frequently used to reduce the intermittent nature of solar energy and guarantee continuous operation. Infrastructure for EV charging usually consists of Level 2 chargers, which use around 30 amps, or 7,200 watts, and can be hardwired or placed as portable units, depending on the location's needs. The possibility for future development, the quality of the land, and the accessibility to the current grid infrastructure are all considerations when choosing locations for solar charging stations. GIS-based multi-criteria decision analysis is frequently used in optimal site selection to balance these variables successfully.

The study sites are diverse, ranging from metropolitan regions with high charging demand to rural places with more land availability but less grid access. Different climates provide different problems. For example, areas that frequently see a lot of rain or cloud cover would need more reliable energy storage options. Solar charging stations have a twofold effect on the power system: they can reduce peak load pressure by distributing energy generation and consumption

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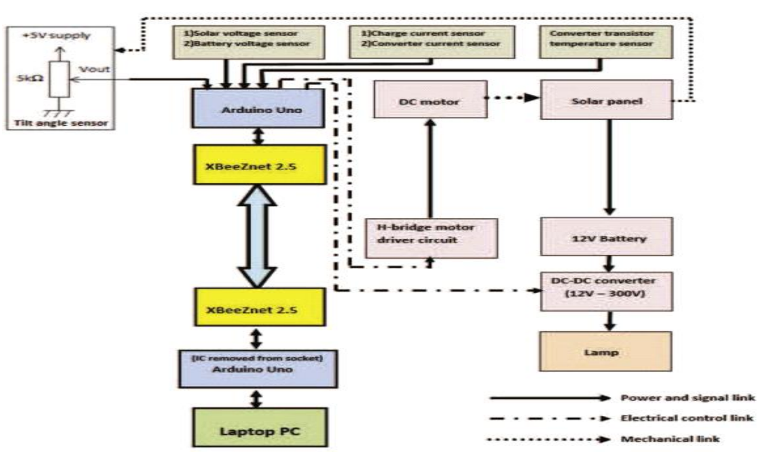
more evenly throughout the day. However, they also require careful planning to prevent overproduction and waste of solar energy during low demand. By incorporating delayed charging systems and smart grid technology, grid strain may be reduced, and efficiency can be further optimized.

Data Collection Methods:

In researching the impact of solar charging stations on the power system, a comprehensive approach to data collection is essential for accurate analysis. Various data types are collected to assess the performance and influence of solar charging stations on the grid[12].

Types of Data Collected:
Power Output: includes the amount of electricity generated by solar panels, which is delivered to the grid or stored in batteries.
Grid Load: Data on the demand and supply balance within the power grid helps manage load distribution.
Voltage Stability: Information on voltage levels to ensure they remain within safe operational limits.
Current Flow: Measurements of current at various points in the system to monitor and control power conversion and distribution.
Solar Irradiance: The amount of solar energy received per unit area is crucial for predicting power generation potential.

Instruments and Sensors Used:
Photovoltaic Panels: capture solar energy and convert it into electrical power.
Inverters: Convert the D.C. output from solar panels into A.C. for use in the grid.
Current Sensors: Measure current flow by monitoring voltage drops across shunt resistors or magnetic fields generated by current flow.
Voltage Sensors: Monitor voltage levels to ensure stability and safety.
Meteorological Instruments: Measure solar irradiance, temperature, and other weather-related data that affect solar power generation



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Data Collection Methods and Tools:
Surveys and Reports: Annual and monthly surveys such as the Electric Generators Survey (EIA-860) and Power Plant Survey (EIA-861) collect detailed data on power generation and consumption.
Real-Time Monitoring Systems: Instruments like the Baseline Measurement System provide live solar radiation data, while the Measurement and Instrumentation Data Center offers irradiance and meteorological data from various stations.
Portable Solar Chargers: These are usedThese are used in field data collection to ensure that devices remain powered in areas with minimal access to electricity[19].

Period of Data Collection:
Data collection to assess the impact of solar charging stations on the power system is typically ongoing. Historical data can span several decades, while real-time data collection occurs continuously. For example, the National Renewable Energy Laboratory (NREL) provides historical measurements from 1981 and live data from approximately 70 instruments on its campus[14].
In summary, integrating solar charging stations into the power system requires meticulous data collection across various parameters using specialized instruments and sensors. Data sources range from historical databases to real-time monitoring systems, ensuring a comprehensive understanding of solar energy's impact on the grid.

Data Analysis:

Statistical analyses play a crucial role in understanding the effects of solar charging stations on the electricity grid. These analyses, which include the examination of voltage profiles and harmonic distortion in power quality analysis, are essential for evaluating the impact on grid stability. They also help in assessing voltage and frequency stability under various conditions using load flow and grid stability analyses[13]. The economic feasibility of solar charging stations is determined through rigorous cost-benefit analysis, which includes income production and net current cost computations. Furthermore, the effect on power prices is carefully evaluated.
Researchers frequently adapt their methods, using sensitivity analysis to consider a range of scenarios with varying degrees of EV penetration and solar panel layouts. This flexibility ensures data dependability and confirms conclusions, providing a nuanced understanding of how, in various scenarios, solar charging stations affect the electrical grid. Additionally, researchers may employ statistical techniques like hypothesis testing and regression analysis to derive conclusions from the data and find correlations between variables. By integrating these methods, researchers can account for system uncertainties and variabilities and comprehensively assess how solar charging stations affect grid stability, electricity quality, and economic aspects.

Result & Discussion:

HOMER Grid:Net present cost and Annualized cost of system:

HOMER (Hybrid Optimization Model for Electric Renewables) uses the total net present cost (NPC) to reflect a system's life-cycle cost. The NPC, which comprises all expenditures and income throughout the project, such as the original capital outlay, component replacements, upkeep, fuel, and grid-supplied electricity, is a powerful tool that allows comparisons between various system setups and technological advancements. This comprehensive metric empowers the audience to make informed decisions and confidently navigate the complex landscape of renewable energy systems[15].
The annualized cost, derived from the NPC, plays a crucial role in comparing solutions with varying lifespans and understanding the system's annual economic impact. HOMER achieves this by converting the present value into a series of equal annual payments over the project lifespan, using the capital recovery factor. In HOMER's optimization process, the annualized cost and net present condition (NPC) are pivotal metrics that assist in ranking various system configurations and identifying the most economical solutions for specific restrictions and sensitivities.Table 1 and 2 . Briefly explain the NPC and ACS system;

Table 1. Net present cost of the system:

Name	Capital	Opening	Replacement	Salvgae	Total
PV	$52,500	$19.39	$.00	$.00	$52,519
Grid	$.00	-$536,827	$.00	$.00	-$536,827
Converter	$35,522	$.00	$15,071	-$2,837	$47,756
System	$8,02	-$536,071	$15,071	-$2,837	-$436,552

Table 2: Annualized cost of system:

Name	Capital	Opening	Replacement	Salvgae	Total
PV	$40,61	$1.50	$.00	$.00	$40,63
Grid	$.00	-$41,526	$.00	$.00	-$41,526
Converter	$2,748	$.00	$1,166	-$219,42	$3,694
System	$6,809	-$41,524	$1,166	-$219,42	-$33,769

Comparison of base case and proposed system:
In comparing the base case with the proposed system using HOMER (Hybrid Optimization of Multiple Energy Resources) to assess the impact of solar charging stations on the power system, critical differences in system performance and efficiency are revealed. The base case typically represents the current grid configuration without solar charging stations, relying on

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conventional energy sources and exhibiting traditional load profiles and cost structures[16]. In contrast, the proposed system incorporates solar charging stations, introduces renewable energy sources, and potentially integrates energy storage solutions. Table 3. Compared it.

	Base system	Processed system
CO2 emitted	20,430	1,676
Net present cost	$83,579	$43,6552
CAPEX	$.00	$88,022
OPEX	$6,465	$40,578
Annual energy change	$6,465	$41,526
LCOE per KWH	$.200	$.139

This shift often significantly reduces reliance on fossil fuels, leading to lower operational costs and decreased greenhouse gas emissions. The proposed system usually demonstrates improved grid stability and resilience, as solar charging stations can generate distributed power and alleviate peak load demands. HOMER's analysis highlights these benefits by comparing metrics such as total system cost, reliability indices, and environmental impact between the base case and the proposed setup. Overall, integrating solar charging stations in the proposed system often results in enhanced economic and ecological outcomes, compelling the case for their adoption in modern power grids.

Cost analysis of proposed system:

The cost analysis of implementing solar charging stations for electric vehicles (EVs) reveals immediate and long-term financial impacts on the power system. Initially, the setup costs for a solar EV charging system can range from $6,500 for a basic setup to over $20,000 for an optimized system with intelligent charging and energy management features. Despite the high upfront costs, these systems offer significant long-term savings by reducing reliance on grid electricity. This can lead to annual savings of around $675.98, with a potential payback period of 5 to 14 years, depending on location and system optimization. Additionally, strategically placing solar charging stations plays a crucial role in enhancing grid stability by mitigating the need for new power plants and utilizing midday solar energy, thus reducing peak evening loads. This approach not only lowers operational costs but also supports environmental goals by reducing greenhouse gas emissions and promoting renewable energy use[18].

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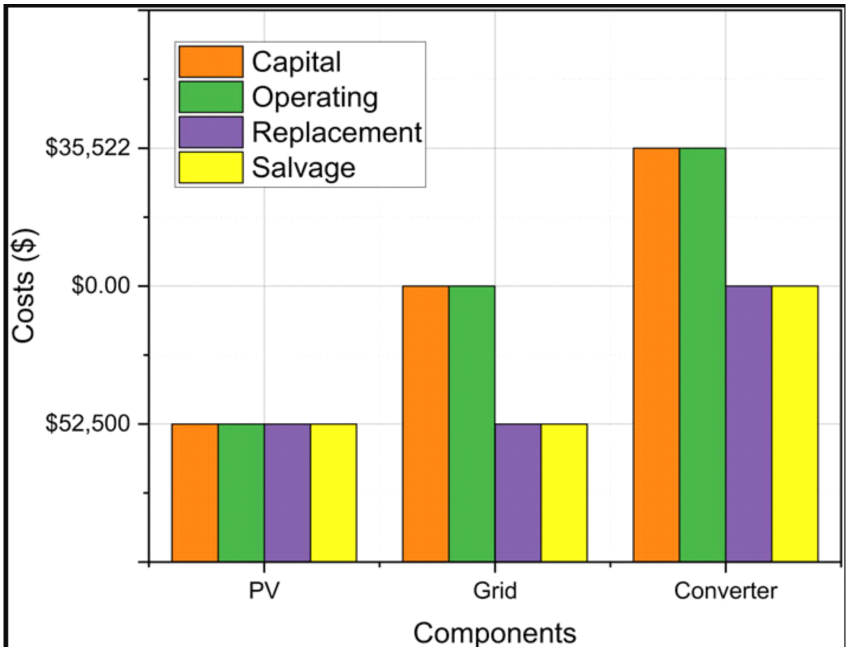

Fig 2.Cost analysis of proposed system:

Production and consumption summary:

Component	KWh\yr	percent
PV- module	254,030	90
Power grid	2,625	10
total	256,683	100
AC load	0	0
Grid sales	210,282	86.7
EV charger served	33,236	13.3
total	242,608	100

HELIOSCOPE:

Comparison of Annualized And Monthly PV production:

By comparing the yearly PV production and monthly production, and leveraging the insightful data from HelioScope, we can gain a comprehensive understanding of the influence of solar charging stations on the power system. This data is crucial for understanding the system's operation and its effects on the grid, empowering us with essential insights.

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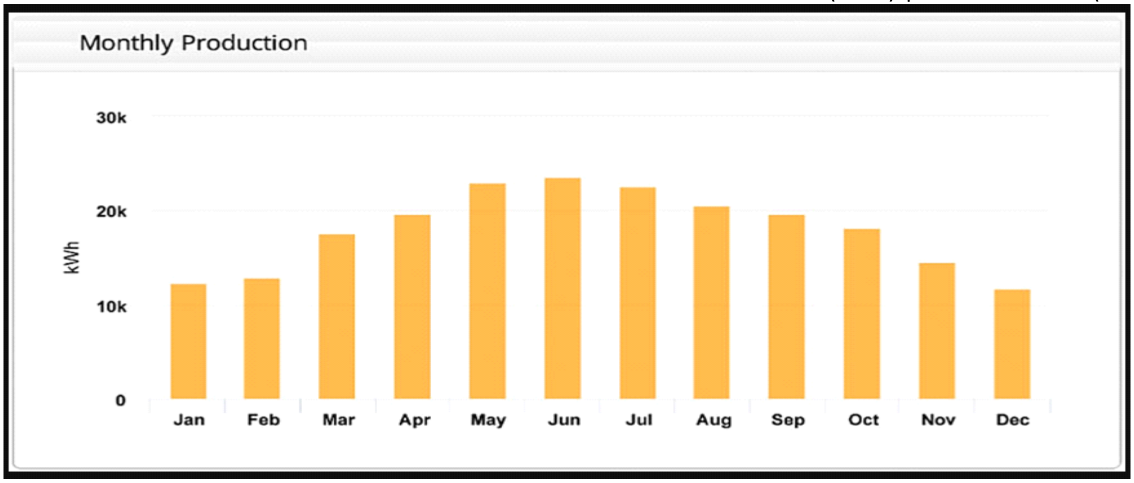
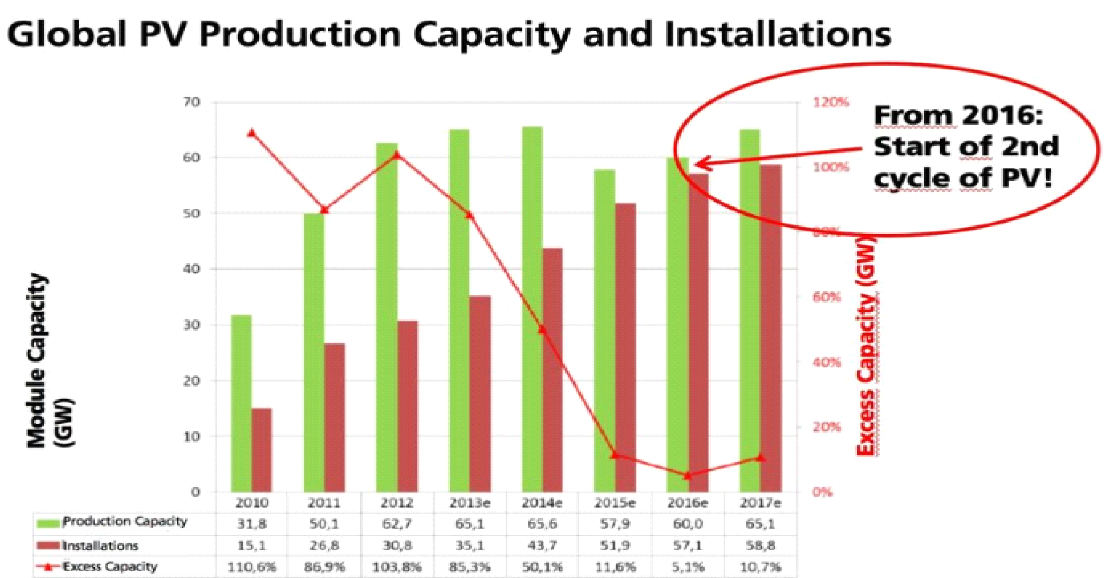


The annualized PV production provides an overview of the system's annual energy generation and a high-level comprehension of the solar charging station's contribution to the power system. This statistic is helpful for long-term planning and evaluating the total influence on the energy supply. However, the monthly output data from HelioScope provides a finer-grained perspective, exposing seasonal variances and perhaps annual swings in energy generation. Comprehension of the month-to-month effects of solar charging stations on the stability and load management (the process of balancing the supply and demand of electricity) of the electricity grid requires a thorough understanding of this breakdown. Examining annualized and monthly production data helps planners and grid operators better predict and prepare when solar energy generation is high or low. This makes it possible to integrate solar charging stations into the current power infrastructure more successfully and maximizes their impact on the overall performance and reliability of the system[17].



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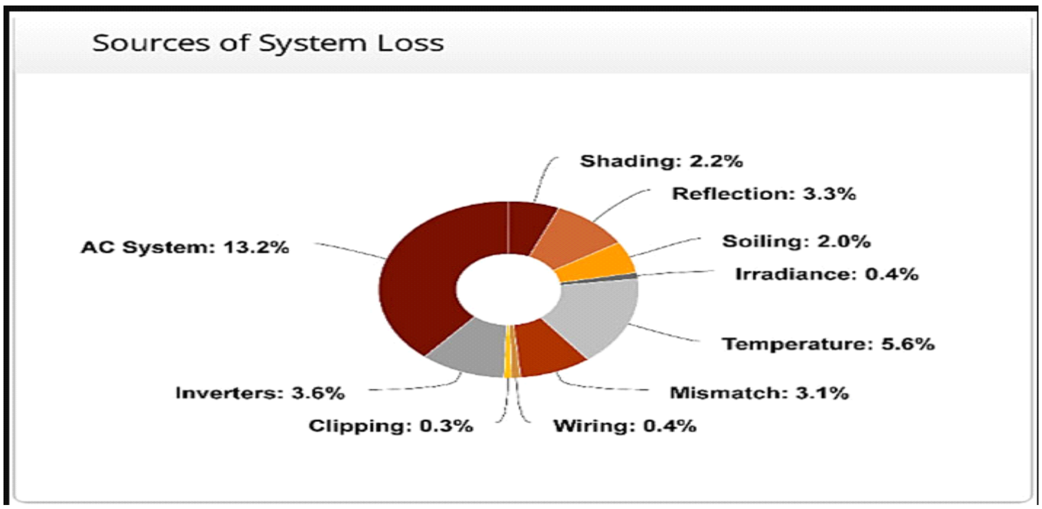
Losses in proposed system:

HelioScope, a solar design software, accounts for various losses in proposed photovoltaic systems to provide accurate energy production estimates. When designing solar charging stations, HelioScope considers factors such as soiling, shading, temperature effects, and system degradation to calculate the overall system efficiency. These losses directly impact the power output of solar charging stations, which in turn affects their integration into the broader power system. Solar charging stations can help reduce grid strain during peak hours by providing localized energy generation and storage capabilities. However, the intermittent nature of solar power and the varying efficiency of these stations due to system losses can present challenges for grid operators in terms of load balancing and power quality management. Accurate modeling of these losses using tools like HelioScope is crucial for predicting the actual impact of solar charging stations on the power system and for optimizing their design and placement to maximize benefits while minimizing potential disruptions to grid stability[20].



Conclusion:

Solar charging stations offer significant benefits to power systems, including enhanced stability and reduced peak demands. To maximize these benefits, ongoing research should focus on improving grid management strategies and advancing energy storage technologies. The system's feasibility is assessed using HOMER Grid software and verified with Helioscope. HOMER Grid estimates an energy production of 254,030 kWh/yr, while Helioscope predicts 215,945 kWh/yr, with the difference attributed to system power losses considered by Helioscope but not by HOMER. Helioscope forecasts system losses of 34.1% due to temperature effects, inverter inefficiencies, and AC system losses. Both tools analyze the monthly power output of the photovoltaic systems. The system is projected to generate $436,552 in revenue after covering installation costs. Of the generated energy, only 13.3% is used for charging, with the remaining 83.7% sold back to the grid. Additionally, energy prices have decreased from $0.20/kWh to $0.016/kWh. Your expertise will be crucial in future evaluations that will focus on how solar charging station integration impacts the power distribution network, particularly addressing voltage variations and power losses associated with solar-powered charging stations.

Author Contribution Statement

Maher Un Nisa Tariq: Conceptualization, Methodology, Resources, Writing- review & editing. **Muhammad Kashif**: Supervision, Experiments, Methodology, Writing-original draft, Review and Suggestion. **Mahnoor Malik**: Methodology, Formal analysis, Writing-original draft. **Nimra Shahzad**: Methodology, Resources, Data Curation, Formal Analysis. **Maira Khalid**: Experiments, Methodology, Formal analysis. **Muhammad Farhan Aslam:** Experiments, Methodology, Formal analysis, **Murad Khan:** Revision draft.

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Author Disclosure Statement

No competing financial interests exist.

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