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User-Centric Adaptive Charging System: Enabling Personalized Charging in Electric Vehicle Chargers

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ABSTRACT

The future of energy is undoubtedly electric, with electric vehicles (EVs) becoming more common. This shift towards using more electricity is driving up demand. However, the increasing use of renewable energy sources, which depend on the weather, adds complexity and unpredictability to electricity production. Our current electricity grid is struggling to keep up, especially with the high energy demands of EVs during peak hours. To address this challenge, smart charging solutions are essential. Smart charging optimizes energy usage by adjusting when and how long EVs are charged. This not only supports sustainable energy sources but also reduces costs and maximizes the use of home-based renewable energy resources like solar panels. Various smart charging strategies include scheduled charging using Variable Rate Tariffs (VRT), charging to make the most of local solar power, and charging with Energy Demand Control (EDC) systems that adjust sessions in real time. IoT technology enhances the intelligence of EV charging stations, allowing for real-time data and control, which significantly improves user experience and energy management [1]. In Pakistan, a roadmap for home based smart charging has been proposed. It outlines three key steps: promoting regulated electricity consumption, maximizing solar power use, and enabling self-sufficient home energy systems. This plan supports Pakistan's goals for low carbon emissions and sustainable energy use by integrating EVs into decentralized energy grids. Analysis of

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available VRT tariffs has identified two promising options: the Short Peak Tariff, which offers low prices during off-peak hours, and the Daytime Plunge tariff, which provides low prices during late night and daytime hours. These align with peak solar power production and lower energy prices, making them ideal for smart charging.

Introduction

Research Framework

Research shows that over half of electric vehicle (EV) users prefer to charge at home. With more EVs hitting the roads, the demand for charging is putting a significant strain on our electricity networks. This surge in charging activity leads to higher peak energy demand and congestion within the distribution grid. Additionally, as the future of energy supply shifts towards sustainability and relies more on renewable sources, we face new challenges. Renewable energy, unlike fossil fuels or coal, is subject to weather-related fluctuations, adding to the imbalance between energy supply and demand, especially with the rising energy needs of EVs. To tackle these challenges and enhance the flexibility of our electricity networks, smart charging for EVs is crucial. Smart charging involves adjusting the speed and timing of EV charging sessions to alleviate congestion, support the integration of renewable energy sources like wind and solar power, reduce costs, and maximize the use of home-based renewable energy systems, such as solar panels. Integrating renewable energy sources with user-centric EV charging can significantly reduce costs and emissions, providing a sustainable and efficient charging solution [20]. Adaptive charging systems can dynamically adjust based on real-time energy availability, maximizing the use of renewable energy and providing a personalized user experience [2]. Various stakeholders play integral roles in EV charging, including grid operators, EV manufacturers, and users. These stakeholders encompass energy producers, suppliers, transmission and distribution network operators, aggregators, government bodies, regulatory agencies, carmakers, charging station operators, and diverse groups of end-users. The increasing demand for EVs presents both opportunities and challenges for energy management systems. As EVs become more prevalent, the need for efficient and adaptive charging solutions grows. This research explores developing a user-centric adaptive charging system designed to provide personalized charging experiences for EV users. The system leverages advanced power electronics, control mechanisms, and user interfaces to optimize charging sessions according to user preferences and grid conditions.

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As real-time adaptive charging management adjusts to user requirements and grid conditions, ensuring efficient and user-tailored charging sessions [9].

Problem Statement

The growing popularity of electric vehicles (EVs) is causing a spike in peak energy demand, leading to congestion in the distribution grid. On top of this, our shift towards renewable energy sources brings variability and unpredictability to electricity production. To tackle these issues, we need smart charging solutions that can adjust to changing grid conditions and user needs. Smart charging is essential for supporting the energy transition at multiple levels. On a national scale, it promotes the adoption of sustainable energy sources. Regionally, it helps alleviate grid congestion. Locally, it ensures a sustainable energy supply for homes.

In Pakistan, there is a strong desire to implement smart charging for future customers. However, there is still uncertainty about how to design an effective system. This challenge underscores the importance of developing tailored solutions that meet the specific needs of the country's energy infrastructure and consumers. Consequently, the following questions arise:

1. How can Pakistan develop an attractive proposition for EV drivers to use home charging solution?
2. What preferences and barriers do EV drivers encounter regarding smart charging solutions?
3. How can energy providers establish and deliver a viable smart charging proposition?
4. What is awareness level of end users?
5. What prerequisites must be met for widespread adoption of smart charging?
6. How can a smart charging proposition be tailored to include new Variable Rate Tariffs (VRT) and provide financial incentives for charging via solar power?

Aim and Objective

To propose a practical and appealing solution for EV users to utilize home smart charging. We need to outline a clear and phased strategy that highlights immediate benefits and sets the groundwork for long-term success in Pakistan. Firstly, let's focus on the immediate benefits for EV drivers. Implementing smart charging at home can help drivers save money by taking advantage of lower electricity rates during off-peak hours. It can also reduce the strain on the grid, leading to more reliable electricity service for

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everyone. Additionally, smart charging can optimize the use of renewable energy sources, such as solar panels, making EV charging more sustainable and environmentally friendly.

Literature Review

This section gives an overview of the research on EV drivers, smart charging, and related concepts like adaptive charging and energy costs. Right now, most full electric vehicle (EV) owners globally are innovators and early adopters, with 91% being male and over half aged between 40 and 60. However, this is changing as EV technology improves, with longer ranges and more options becoming available, leading to a more diverse group of EV drivers. The state-of-the-art in EV technologies highlights the importance of user-centric charging systems in enhancing the efficiency and appeal of electric vehicles [19]. My paper focuses on EV drivers who can charge their vehicles at home, usually those with access to a private driveway. This means that broader demographic changes may not have a direct impact on this specific group. Many car manufacturers now offer apps that let users set charging schedules, making it easier to charge during off-peak hours to save money or help balance the grid. Notable energy suppliers in the smart charging field include Elli (Volkswagen's energy subsidiary), Shell Energy, and LeasePlan Energy. LeasePlan Energy provides comprehensive smart charging solutions for lease drivers, while companies like Jedlix, Stekker, and Gridio offer dynamic charging solutions independently of car manufacturers or energy suppliers. An analysis of apps from leading EV brands shows that they generally offer similar features. Users can set timeframes or create weekly schedules for charging, specifying departure times, start times, or off-peak hours. Some apps even prioritize off-peak charging. For instance, Tesla's app allows users to adjust the charging rate, while apps from Hyundai and Renault let users set a desired battery percentage for immediate charging before switching to smart charging. This research highlights the current landscape of EV ownership and smart charging solutions, emphasizing the importance of adaptive charging to manage energy costs and support the growing adoption of electric vehicles. Several research studies explore different approaches to optimizing electric vehicle charging:

1. Optimization of Electric Vehicle Charging Schedule Using Reinforcement Learning: This research uses reinforcement learning algorithms to optimize charging schedules by taking into account user preferences, energy costs, and grid limitations. The proposed method dynamically adjusts

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charging rates, resulting in significant improvements in both charging efficiency and grid stability.

2. A Genetic Algorithm-Based Approach for User-Centric Electric Vehicle Charging Optimization: This study employs genetic algorithms to create various charging strategies, aiming to balance user convenience and grid reliability.

3. Real-Time Adaptive Charging Management for Electric Vehicles in Smart Grids: This research concentrates on real-time adaptive charging management within smart grids, incorporating vehicle-to-grid (V2G) capabilities and advanced control algorithms. The system has demonstrated enhanced grid stability and lower energy costs.

4. Machine Learning-Based User-Centric Charging Optimization for Electric Vehicles: The study explores using machine learning techniques to optimize charging based on user preferences. By generating personalized schedules, it aims to enhance both user satisfaction and grid efficiency.

5. Dynamic Pricing Strategies for User-Centric Electric Vehicle Charging: This research looks into dynamic pricing strategies that align charging costs with grid conditions and user preferences. The findings show potential for cost savings and better grid utilization.

6. Enhancing Grid Stability Through User-Centric Electric Vehicle Charging Control: The study examines how user-centric charging control affects grid stability, revealing that it reduces stress on distribution networks and improves voltage stability.

7. Federated Learning-Based Adaptive Charging System for Electric Vehicle Fleets: This research presents a federated learning-based system designed to optimize charging strategies across entire fleets while maintaining data privacy. Experimental evaluations show that this approach is both scalable and efficient.

8. Personalized Electric Vehicle Charging Strategies Considering User Preferences and Grid Constraints: This study proposes a personalized charging strategy that takes into account user preferences and grid constraints. By using machine learning techniques, it adapts charging schedules based on user behavior and real-time grid conditions. The research shows that this approach leads to higher user satisfaction and better grid efficiency compared to traditional charging

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methods.

9. Optimization of Electric Vehicle Charging Schedule Using Reinforcement Learning: This research uses reinforcement learning algorithms to optimize electric vehicle charging schedules. By taking into account user preferences, energy costs, and grid constraints, the proposed method dynamically adjusts charging rates to maximize user satisfaction and minimize grid impact. The simulation results reveal significant improvements in both charging efficiency and grid stability.

10. A Genetic Algorithm-Based Approach for User-Centric Electric Vehicle Charging Optimization: The study introduces a genetic algorithm-based approach to optimize electric vehicle charging schedules. By creating a variety of charging strategies and evaluating them based on user preferences and grid constraints, the method identifies the best charging solutions.

11. Real-Time Adaptive Charging Management for Electric Vehicles in Smart Grids: This research focuses on real-time adaptive charging management for electric vehicles within smart grids. By incorporating vehicle-to-grid (V2G) capabilities and advanced control algorithms, the system adjusts charging rates based on user needs and grid conditions. Experimental validation demonstrates that this approach enhances grid stability and lowers energy costs.

12. Machine Learning-Based User-Centric Charging Optimization for Electric Vehicles: The study explores using machine learning techniques to optimize electric vehicle charging based on user preferences. By analyzing historical charging data and user behavior patterns, the system generates personalized charging schedules.

13. Dynamic Pricing Strategies for User-Centric Electric Vehicle Charging: This research looks into dynamic pricing strategies for user-centric electric vehicle charging. By aligning charging costs with grid conditions and user preferences, these pricing models encourage flexible charging behavior. This approach can lead to cost savings for users and better grid utilization.

14. Enhancing Grid Stability Through User-Centric Electric Vehicle Charging Control: The study examines how user-centric electric vehicle charging control affects grid stability. By coordinating charging schedules to reduce peak demand

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and grid congestion, this approach enhances grid reliability.

15. Predictive Analytics for User-Centric Electric Vehicle Charging Optimization: This research uses predictive analytics techniques to optimize electric vehicle charging schedules proactively. By forecasting user demand and grid conditions, the system anticipates charging needs and adjusts the schedule accordingly.

16. Adaptive Charging Strategies for Electric Vehicle Fleets in Urban Environments: Focusing on urban environments, this study explores adaptive charging strategies for electric vehicle fleets. It takes into account fleet management needs, traffic patterns, and the availability of charging infrastructure. The research proposes dynamic charging schedules to optimize fleet operations and integrate smoothly with the grid.

17. Multi-Objective Optimization of Electric Vehicle Charging Considering User Preferences and Grid Stability: This research tackles the challenge of optimizing electric vehicle charging by balancing user preferences with grid stability. By treating the problem as a multi-objective optimization task, the study explores the trade-offs between user convenience, energy costs, and grid reliability.

18. Energy-Aware Electric Vehicle Charging Management in Smart Homes: This research focuses on smart home environments and proposes an energy-aware charging management system for electric vehicles. By integrating home energy consumption patterns, renewable energy generation, and user preferences, the system optimizes charging schedules to minimize energy costs and reduce carbon emissions.

19. Privacy-Preserving User-Centric Electric Vehicle Charging Optimization: This study tackles privacy concerns by developing privacy-preserving algorithms for optimizing electric vehicle charging. Using cryptographic techniques like homomorphic encryption and secure multiparty computation, the system keeps user data confidential while providing personalized charging recommendations.

20. Agent-Based Modeling of User Behavior in Electric Vehicle Charging Networks: This research uses agent-based modeling techniques to study user behavior in electric vehicle charging networks. By simulating individual user decisions and interactions within the charging ecosystem, the study examines how charging incentives, infrastructure availability, and grid constraints affect overall

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system performance. The findings offer valuable insights for designing effective user-centric charging policies.

21. User-Centric Electric Vehicle Charging Management Considering Renewable Energy Integration: This research explores user-centric electric vehicle charging management strategies, emphasizing renewable energy integration. By aligning charging schedules with renewable energy generation, the proposed approach maximizes the use of clean energy sources and reduces reliance on fossil fuels.

22. Robust Optimization of Electric Vehicle Charging in Uncertain Environment: This study addresses uncertainties in grid conditions and user behavior by investigating robust optimization techniques for electric vehicle charging. By incorporating uncertainty models and scenario analysis, the research develops charging strategies that can adapt to variations in energy prices, demand patterns, and renewable energy availability.

These studies collectively contribute to advancing the state-of-the-art in user-centric adaptive charging systems for electric vehicle chargers, addressing various aspects such as optimization algorithms, grid integration, privacy concerns, and renewable energy integration. By leveraging interdisciplinary approaches and advanced technologies, these research efforts pave the way towards a sustainable and efficient electric vehicle charging ecosystem. Reinforcement learning in EV charging systems can adapt to user behavior, providing a highly personalized and efficient charging experience [7].

Research Methodology

The research is organized into four stages. The first stage delves into the overarching topic of Overview of Intelligent Charging and Pakistan Energy System. In the second phase, the key insights gathered from the initial stage are synthesized, leading to the design phase for smart charging; mechanisms of changing current using power electronics. Third phase involves formulation of solutions, which are then evaluated for their desirability; different approaches to implementing smart charging. Finally, in the fourth phase, all components are integrated, addressing how the proposed design aligns with the defined strategy and what are advanced smart charging techniques. As, smart EV charging systems that focus on user needs can optimize energy use and improve the overall efficiency of the charging infrastructure [21].

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Phase-1: Overview of Intelligent Charging and Pakistan Energy System

Essentially, intelligent charging entails modifying the pace and/or scheduling of an electric vehicle (EV) charging session. There exist various approaches to accomplish this, varying in complexity.

Pakistan Energy System

The focus of this section centers on the energy infrastructure within Pakistan, emphasizing the necessity to outline the overall landscape involving key participants and their interrelations. The transmission network is overseen by a single national entity, namely the Water and Power Distribution Authority (WAPDA), while distribution networks are managed by multiple grid operators such as GEPCO, LESCO, and K-Electric, each serving distinct regions. Consumers are obligated to settle bills for their grid access, directing payments to energy providers. The simplified diagram provided below (Figure 1) illustrates the primary stakeholders and their respective functions.

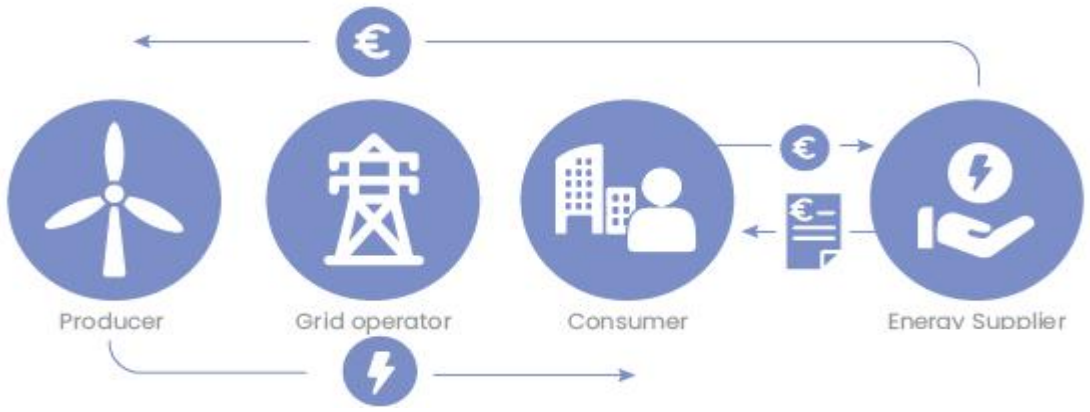


Figure 1: Energy Cycle

Network Congestion

The electricity network has limited capacity, imposing a cap on the maximum electricity it can carry. If the total electricity transported exceeds this limit, network congestion occurs (as shown in Figure 2). To address network congestion, grid operators employ two main strategies. In the long run, they enhance the capacity of critical network components by upgrading network cables. In the short term, they implement congestion management techniques, which may include load shedding or adjusting energy provision or consumption to alleviate congestion in areas where it is expected. To cater this smart charging strategies that consider user behavior and grid load ensure efficient energy use

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and provide a tailored charging experience for each user [3].

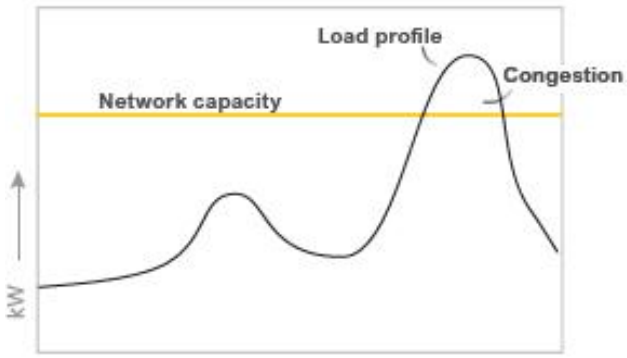


Figure 2: Network Congestion

Main concept to avoid network congestion is implying strategy that avoids current to exceed designated limit. This will definitely affect total charging time of vehicle, but ensures safety of home electrical wiring. It prevents circuit breaker from tripping.

Figure 3 illustrates daily load profile, showing rms current and maximum rms current allowed for a supposed home. A limit has been set as a common value for a home normal electricity usage as 16 Amp/ 230 V. from the graph it is observed that peak current typically occurs after 1700 hours. Suppose that a user has to charge his vehicle from 1900 hours to 0800 hours, an uncontrolled battery charger that starts charging from 1900 hours will cause the breaker to tripping due to overpower/ safety of system as shown in Figure 4. Opposite to that, a user centric battery charging process maintains the limit of current of home below the set value of circuit breaker and avoids trips; depicted in Figure 5. This system will obviously require more time to charge a vehicle but will ensures safety of the system.

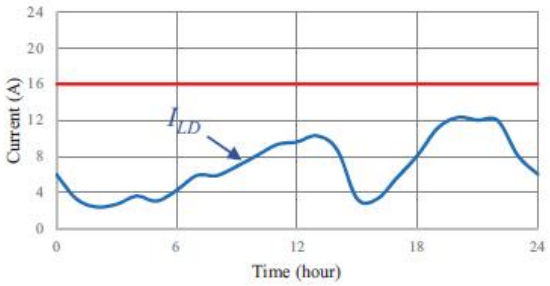


Figure 3: load current of home without battery charger incorporation

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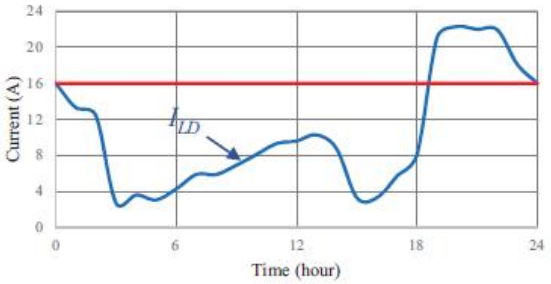


Figure 4: load current profile of home; Battery charger without control

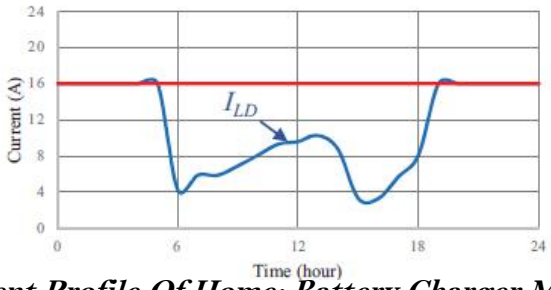


Figure 5: Load Current Profile Of Home; Battery Charger Managing Congestion

Energy Tariffs

Consumers are charged for their electricity usage based on energy tariffs, which determine the price per kilowatt-hour (kWh) or unit of energy consumed. The tariff structure plays a significant role in determining the cost of electricity for consumers. Broadly speaking, there are two main types of tariff structures: flat tariffs, also known as single tariffs, and Variable Rate Tariffs (VRT) tariffs, which encompass a range of possible tariff structures (as depicted in the figure 4). Unlike flat tariffs, where the price remains constant, VRT tariffs feature varying energy prices, with consumers paying the rate applicable during the specific time period when electricity is consumed. In Pakistan, energy providers predominantly offer flat tariffs, alongside a static VRT tariff. Presently, the static VRT available in Pakistan is segmented into bi segments, with hours controlled by energy providers. Off-peak hours typically span from 10:00 PM to 6:00 AM.

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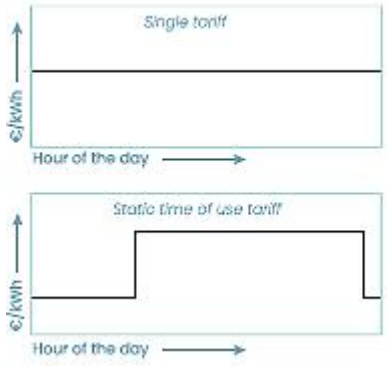


Figure 6: Tariff Cycle

Home Solar System

Solar energy produced by rooftop photovoltaic panels plays a vital role in the deployment of smart charging systems. Many EV owners who charge their vehicles at home are anticipated to have their own solar panel installations. The "Green-meter" concept is crucial in solar energy utilization. In the traditional setup, electricity from the grid flows through the meter and into the household. However, with the Green-meter setup, electricity generated by rooftop solar panels bypasses the meter and directly energizes household appliances. Only excess solar power beyond immediate household needs is routed back through the meter and into the grid. (As depicted in Figure 5).

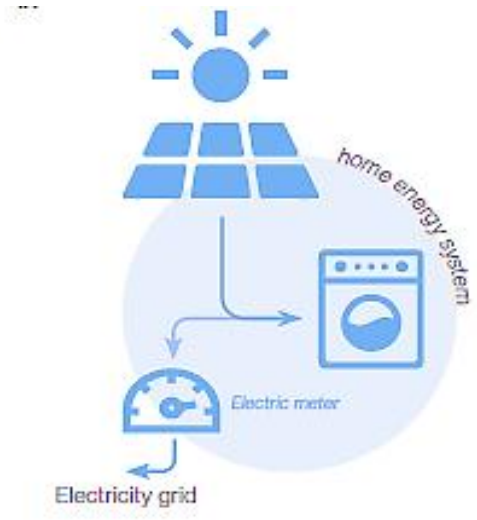


Figure 7: Energy Flow Cycle

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Phase 2: Mechanisms of Changing Current Using Power Electronics

On-Board Charging

On-board charging is the most common method for light electric vehicles (LEVs) because of its compact size and easy access to power. Typically, an AC-based LEV charging system involves two stages: first, AC-DC rectification followed by DC-DC power factor correction (PFC) to ensure a smooth input current, and then another DC-DC converter to handle battery charging. Researchers have also created single-stage LEV chargers, where one DC-DC converter manages both PFC and battery charging. These on-board chargers can be integrated into the vehicle or included in the charging cable. The primary design goal is to make these chargers as compact as possible to increase power density and save space. Key features include high charging efficiency, high power density, and a good input power factor.

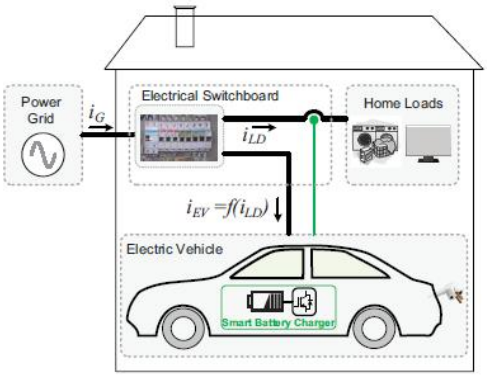


Figure 8: On Board Charging

In a typical AC-based charging system for light electric vehicles (LEVs), an AC-DC rectifier smooths the input current, and a DC-DC converter manages the battery charging.

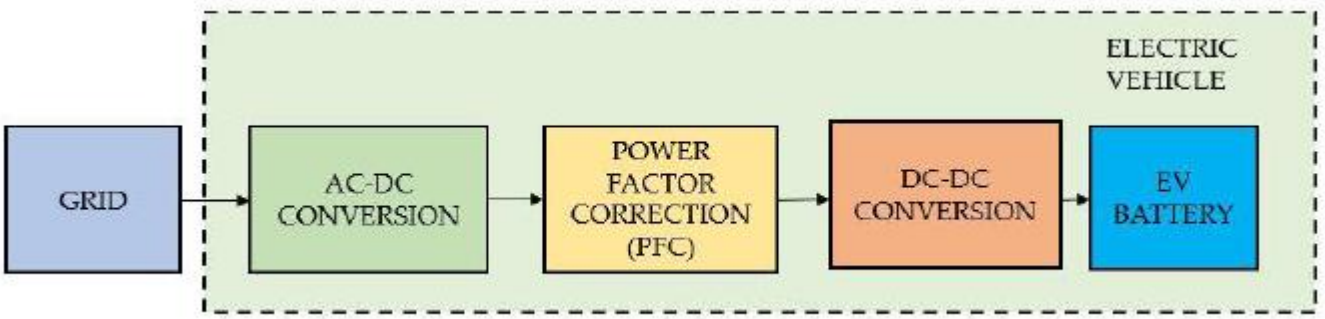


Figure 8: On Board Charging

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Isolated DC-DC Converters

In LEV chargers, isolation can be achieved either through a transformer located at the supply end or integrated within the converter itself. Due to the impractical size of supply-side transformers, researchers have shifted to high-frequency transformers known for their compact design. Isolation in converters provides several advantages, including enhanced user safety by ensuring galvanic isolation between the battery circuit and the power supply. Moreover, the turns ratio of high-frequency transformers can be adjusted to widen the voltage gain range, making the converter suitable for a broader range of loads.

Off-Board Charging

Researchers are exploring DC charging for light electric vehicles (LEVs). These chargers are often situated off the vehicle and might not incorporate a dedicated power factor correction (PFC) stage, aiming to enhance charging efficiency. This approach is particularly suitable for integration into DC micro-grid systems, reducing dependence on the AC power grid.

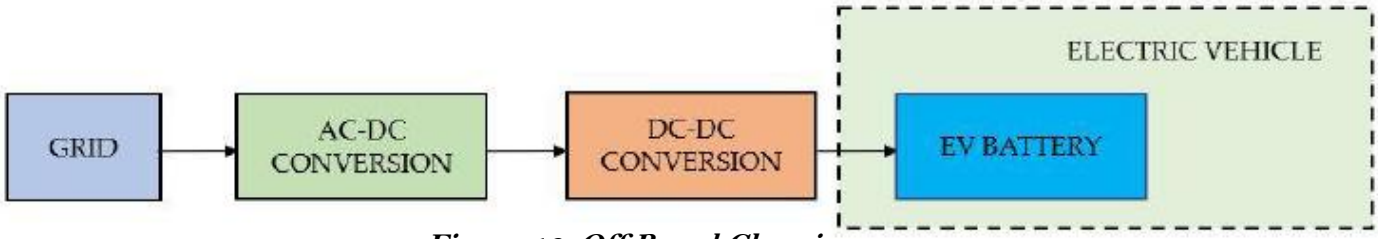


Figure 10: Off Board Charging

Bridgeless Converters

Researchers are using bridgeless converter designs to reduce the number of semiconductor devices in charger systems. For example, a single-stage bridgeless isolated positive output Luo converter for charging light electric vehicles (LEVs) ensures a high-power factor using a specialized AC-DC converter setup based on Luo converter technology. This design eliminates the front-end diode bridge rectifier, simplifying the circuit and reducing component count. The Luo converter-based topology also achieves a positive output polarity, making it easier to design the output sensor. Operating in discontinuous mode, this converter reduces the size of magnetic components and lowers switching and conduction losses.

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Design Phase

The shift towards electric vehicles (EVs) marks a significant move towards sustainable transportation, emphasizing the need for efficient EV charging systems that cater to various user requirements. Personalized EV charging, allowing users to adjust the charging current, plays a crucial role. Optimal voltage control in EV charging stations integrates renewable energy sources and provides a more efficient and personalized charging process [3].

Designing Parameters

A user-friendly interface is essential for personalized EV charging. It should enable users to easily adjust the charging current, set schedules, and monitor the charging process effortlessly.

Features of an Effective Interface

- **Real-time Current Adjustment**: Users can increase or decrease the charging current in real time.
- **Charging Profiles**: Users can create profiles for different charging scenarios.
- **Usage Statistics**: The interface provides data on energy consumption and charging history.

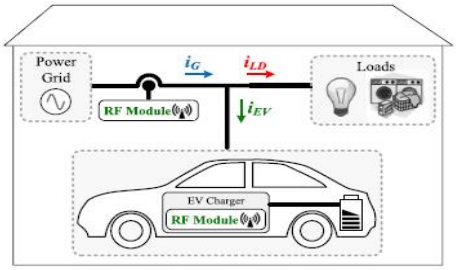


Figure 11: Interfacing Flow

Construction of a User-Centric Adaptive Charging System

The construction of a user-centric adaptive charging system involves several critical components:

1. Power Supply
2. EMI Filter
3. AC-DC Rectifier
4. Power Factor Correction (PFC) Circuit
5. DC-DC Converter

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6. Battery Management System (BMS)
7. Control and Monitoring System
8. User Interface

EMI Filter

The EMI (Electromagnetic Interference) filter is designed to suppress high-frequency noise generated by the charger's switching circuits. This helps prevent interference with other electronic devices and ensures the charger complies with regulatory standards.

1. **Common Mode Choke (CMC)**: This component suppresses common mode noise, which is the noise present on both power lines relative to the ground.

2. **X Capacitors**: Placed between the live and neutral lines, these capacitors filter differential mode noise, which is noise between the power lines.

3. **Y Capacitors**: Placed between the power lines and the ground, these capacitors help in filtering common mode noise.

Power Supply

The power supply for an EV charger can be derived from a standard AC mains outlet. The voltage and current ratings depend on the specific requirements of the EV battery.

AC-DC Rectifier

The AC-DC rectifier converts the AC input from the mains supply into a DC voltage. The output of the rectifier is a pulsating DC voltage, which needs to be smoothed using capacitors.

Power Factor Correction (PFC) Circuit

Power Factor Correction (PFC) is essential for improving the efficiency of the charging system and reducing the harmonic distortion in the input current.

DC-DC Converter

It is the heart of the EV charger. It converts the rectified DC voltage to an optimum level for charging. Its design requires some careful considerations e.g desired voltage conversion ratio, efficiency, and size constraints.

❖ **Isolated DC-DC Converters**

Isolated DC-DC converters use transformers to create a safe separation between the input and output, which enhances safety and allows for a wider range of voltage conversion. Common types of these isolated converters are:

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- **Flyback Converter**: Suitable for low to medium power applications, the Flyback converter is simple and cost-effective but has limitations in terms of efficiency and output power.
- **Forward Converter**: Offers better efficiency and output power capabilities than the Flyback converter. It is suitable for medium power applications.
- **Push-Pull Converter**: Provides high efficiency and is suitable for higher power applications. It requires a center-tapped transformer and is more complex to design.
- **Half-Bridge Converter**: Suitable for medium to high power applications, offering good efficiency and power density. It requires two switching devices and a center-tapped transformer.
- **Full-Bridge Converter**: Ideal for high power applications, providing excellent efficiency and power density. It is more complex and requires four switching devices.

❖ **Non-Isolated DC-DC Converters**

❖ Non-isolated DC-DC converters, which do not use transformers, are generally simpler and more compact. Common types are:

- **Buck Converter**: Used for step-down voltage conversion, suitable for applications where the input voltage is higher than the output voltage.
- **Boost Converter**: Used for step-up voltage conversion, suitable for applications where the input voltage is lower than the output voltage.
- **Buck-Boost Converter**: Capable of both step-up and step-down voltage conversion, suitable for applications where the input voltage can vary above and below the output voltage.
- **Cuk Converter:** Provides both step-up and step-down conversion with continuous input and output currents, reducing current ripples.
- **SEPIC Converter**: Similar to the Cuk converter, but with easier control and design flexibility.
- **Zeta Converter**: Similar to the SEPIC converter, with continuous output current and good ripple rejection capabilities.

Battery Management System (BMS)

The Battery Management System (BMS) plays a crucial role in monitoring and managing the state of an EV battery during charging. It ensures the battery is charged safely and

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efficiently by keeping track of parameters like voltage, current, temperature, and state of charge (SOC). The BMS also protects the battery from overcharging, over-discharging, and overheating.

Control and Monitoring System

The control and monitoring system oversees the overall operation of the charger. It communicates with the Battery Management System (BMS) to receive battery status information and adjusts the charging parameters as needed. This system can be implemented using microcontrollers or digital signal processors (DSPs), which run the control algorithms and offer user interfaces for monitoring and diagnostics. When selecting a microcontroller, it's important to choose one with enough I/O pins, processing power, and peripherals. Popular options include STM32, Arduino, and PIC microcontrollers. Secure communication protocols are essential for user-centric charging systems, ensuring both efficiency and privacy in advanced metering infrastructure [22].

Microcontroller -----> Display

|--> Buttons for User Input

|--> Voltage/Current Feedback from Sensors

|--> Control Signals to PFC and DC-DC Converter

|--> Communication Interface (CAN/UART)

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Design and Construction Process

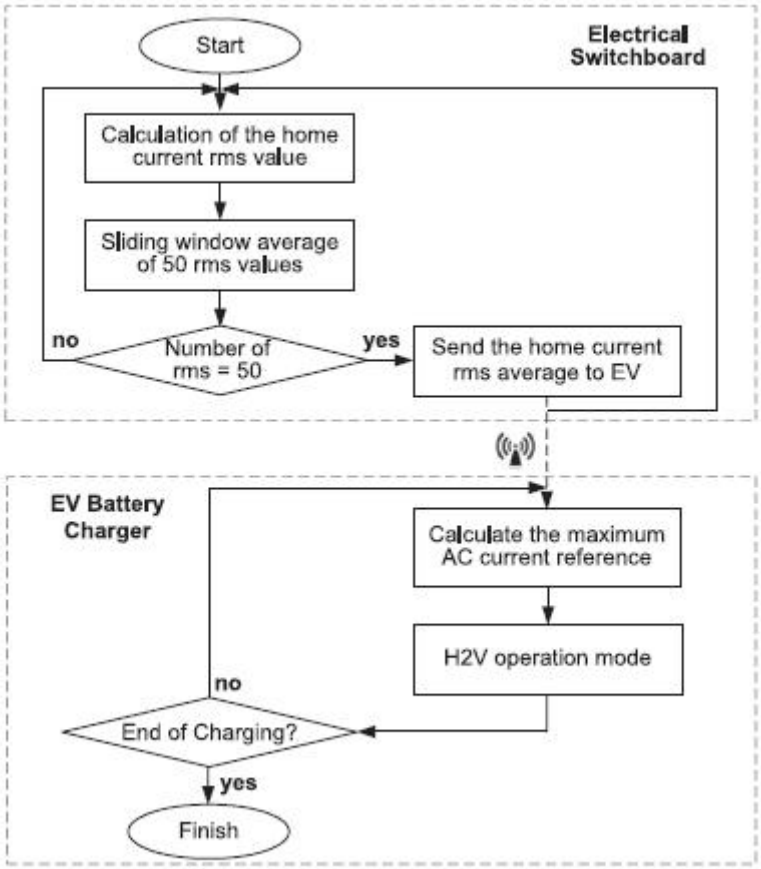


Figure 12: Flow diagram Home to Vehicle Charging Operation.

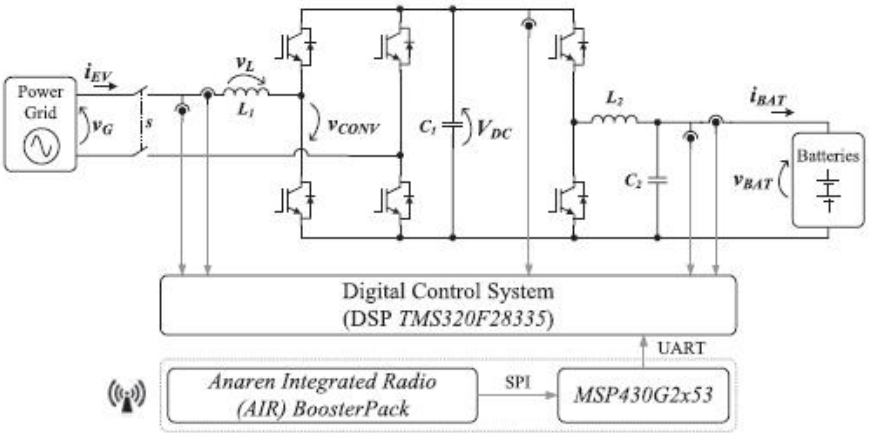


Figure 13: Circuit diagram of the Electric Vehicle battery charger with communication.

Figure 13 presents the Circuit diagram of an example of Electric Vehicle battery charger with communication system. Two radio frequency communication modules are integrated,

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first into the home electrical switchboard, being used as a transmitter to wirelessly send information to the battery charger. Second module as receiver is built into the battery charger. Switch is used to connect or disconnect charger from the grid, and the charger automatically disconnects in the event of voltage sags or swells.

Design Process

Select DC-DC Converters

Based on the specifications, select an appropriate DC-DC converter topology. The choice of topology depends on factors such as the desired voltage conversion ratio, isolation requirements, efficiency, and size constraints.

Design the Converter Circuit

After selecting the topology, the next step is to design the converter circuit. This involves choosing components like inductors, capacitors, transformers (for isolated topologies), and switching devices such as transistors or MOSFETs.

Component Selection

Inductors and Transformers: Select inductors and transformers based on the needed inductance, current rating, and core material. For isolated topologies, design the transformer with the correct turns ratio to achieve the desired voltage conversion.

Capacitors: Select capacitors for input and output filtering to reduce voltage and current ripples. Consider the voltage rating, capacitance value, and equivalent series resistance (ESR).

Switching Devices: Choose switching devices (e.g., MOSFETs, IGBTs) based on their voltage and current ratings, switching speed, and thermal performance.

Implement Control and Feedback Mechanisms

Design the control and feedback mechanisms to regulate the converter's operation and ensure a stable output voltage and current. This includes implementing control loops, such as voltage mode control or current mode control, along with feedback circuits.

Feedback Circuit Design: Implement feedback circuits using sensors, such as voltage dividers and current shunts, along with signal conditioning circuits like operational amplifiers. These components provide accurate feedback signals to the control loop, ensuring precise regulation of the converter's operation.

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Advance Current Sensors

The latest EV charging solutions rely on precise current sensing to ensure accuracy, reliability, and safety as adoption rates surge. As the use of EVs increases, minimizing charging times and enhancing battery efficiency and safety become paramount. Correct current-sensing methods address concerns like inefficient operation and shortened lifespans, which are crucial for the functionality of onboard and power electronics infrastructure. Power electronics converters for EV charging can be optimized for user-centric applications, ensuring efficient and personalized charging sessions [18]. Advanced current measurement solutions enable optimal performance, efficiency, and thermal management, allowing for early fault detection and real-time performance monitoring in EV charging systems. While basic shunt-based methods offer decent performance, they struggle with extreme currents and thermal challenges. Hall sensors provide isolation but lack accuracy, and current transformers are too bulky for compact automotive systems. In contrast, Anisotropic Magnetoresistance (AMR) based sensors offer galvanic isolation, fast and accurate readings, and offset correction, delivering integrated solutions that reduce footprint and enhance performance. These sensors meet the evolving demands of higher working voltages in EVs, thereby enhancing overall safety and reliability.

Programming Code

To create a detailed code for user-customized EV charging settings based on time, energy, and tariff requirements, we'll follow these steps:

1. **Create a User Interface**: We'll use a simple command-line interface (CLI) to input the settings.
2. **Store User Settings**: We'll save these settings in a structured format.
3. **Calculate Optimal Charging Schedule**: Based on user input and tariffs, we'll calculate the best times to charge to save cost and battery life.
4. **Simulate Charging**: We'll simulate the charging process based on the calculated schedule.

Complete code in Python:

```python
import json
from datetime import datetime, timedelta
```

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```
# Constants
BATTERY_CAPACITY_KWH = 100  # Example EV battery capacity in kWh
MAX_CHARGE_RATE_KW = 11  # Max charging rate in kW
MIN_BATTERY_PERCENTAGE = 20  # Minimum battery percentage to avoid deep discharge
TARIFFS = {
    "00:00-06:00": 0.1,  # Example tariffs in $/kWh
    "06:00-12:00": 0.2,
    "12:00-18:00": 0.3,
    "18:00-24:00": 0.15}
# Utility Functions
def get_tariff(hour):
    for period, rate in TARIFFS.items():
        start, end = period.split('-')
        if int(start) <= hour < int(end):
            return rate
    return max(TARIFFS.values())
def get_user_settings():
    settings = {}
    settings["desired_energy_kwh"] = float(input("Enter the desired energy in kWh: "))
    settings["end_time"] = input("Enter the end time (HH:MM) for charging: ")
    settings["tariff_preference"] = input("Enter tariff preference (low, medium, high): ").lower()
    settings["preserve_battery_life"] = input("Preserve battery life (yes/no): ").lower() == 'yes'
    return settings
def calculate_charging_schedule(settings):
    current_time = datetime.now()
    end_time = datetime.strptime(settings["end_time"], "%H:%M").replace(year=current_time.year, month=current_time.month, day=current_time.day)
    if end_time < current_time:
```

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```
        end_time += timedelta(days=1)
    remaining_time = (end_time - current_time).total_seconds() / 3600
    desired_energy = settings["desired_energy_kwh"]
    charge_schedule = []
    total_energy = 0
    for hour in range(int(remaining_time)):
        current_hour = (current_time + timedelta(hours=hour)).hour
        tariff = get_tariff(current_hour)
        if (settings["tariff_preference"] == "low" and tariff == min(TARIFFS.values())) or \
           (settings["tariff_preference"] == "medium" and tariff <= 0.2) or \
           (settings["tariff_preference"] == "high" and tariff <= 0.3):
            energy_to_charge = min(MAX_CHARGE_RATE_KW, desired_energy - total_energy)
            if total_energy + energy_to_charge <= desired_energy:
                charge_schedule.append({"hour": current_hour, "energy": energy_to_charge, "tariff": tariff})
                total_energy += energy_to_charge
            if total_energy >= desired_energy:
                break
    return charge_schedule
def simulate_charging(schedule):
    print("Charging Schedule:")
    for entry in schedule:
        print(f"Hour: {entry['hour']}, Energy: {entry['energy']} kWh, Tariff: ${entry['tariff']}/kWh")
    print("Charging simulation complete.")
def save_settings(settings):
    with open('user_settings.json', 'w') as f:
        json.dump(settings, f, indent=4)
def load_settings():
    try:
```

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```
        with open('user_settings.json', 'r') as f:
            return json.load(f)
    except FileNotFoundError:
        return None
def main():
    print("EV Charging Scheduler")
    settings = load_settings()
    if settings:
        print("Loaded previous settings.")
    else:
        settings = get_user_settings()
        save_settings(settings)
    charge_schedule = calculate_charging_schedule(settings)
    simulate_charging(charge_schedule)
if __name__ == "__main__":
main()
```

Explanation of Code

1. **Constants**: Define battery capacity, max charge rate, minimum battery percentage, and tariffs.

2. **Utility Functions**:

- `get_tariff(hour)`: Get the tariff for a specific hour.
- `get_user_settings()`: Prompt user for charging preferences.
- `calculate_charging_schedule(settings)`: Calculate the charging schedule based on user preferences.
- `simulate_charging(schedule)`: Simulate the charging process.
- `save_settings(settings)`: Save user settings to a file.
- `load_settings()`: Load user settings from a file.

Example of an LEV Charger Fabrication

To illustrate the design process, this section presents a case study of designing a 48V LEV charger using an isolated Flyback converter topology.

Specifications

- Input Voltage: 220V AC

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- Output Voltage: 48V DC
- Output Current: 10A
- Efficiency: >85%
- Power Factor: >0.9
- Safety Features: Overvoltage protection, overcurrent protection, thermal protection

Select Flyback Converters

The Flyback converter is chosen for its simplicity and suitability for low to medium power applications. It provides galvanic isolation and can handle wide input voltage variations.

Design the Converter Circuit

- **Transformer**: Design a high-frequency transformer with a turn's ratio of 5:1 to step down the input voltage.
- **Switching Device**: Choose a MOSFET with a voltage rating of 600V and current rating of 15A.
- **Diodes**: Use fast recovery diodes for the rectification stage.
- **Capacitors**: Select electrolytic capacitors for input and output filtering, with appropriate voltage ratings and capacitance values.
- **Inductor**: Choose an inductor with a suitable inductance value for filtering.

Implement Control and Feedback Mechanisms

- Implement a voltage mode control loop using a PWM controller IC. The feedback network senses the output voltage and compares it with a reference value. The error signal is processed by a compensator to generate the control signal for the MOSFET.

Feedback Circuit Design

- Use a voltage divider network to sense the output voltage. The sensed voltage is fed to an operational amplifier for signal conditioning and then to the PWM controller for feedback.

Integration with Smart Devices

The interface can be integrated with a mobile application, enabling users to control their EV charger remotely. This adds a layer of convenience and personalization, as users can manage their charging sessions on-the-go. Some examples are:

Jedlix stands out as a noteworthy contender in competitor analysis due to its

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development of applications for various OEMs (Original Equipment Manufacturers) and energy suppliers. Jedlix dynamically manages charging sessions based on real-time market data, resulting in potential savings on electricity expenses or opportunities to earn revenue. A portion of these savings or earnings is subsequently transferred to the end-consumer.

Stekker represents a third-party entity, independent of both car manufacturers and energy suppliers, that provides optimized charging solutions based on hourly timeframes (as illustrated in figure 6). To utilize this service, users must have a contract with dynamic energy pricing. While dynamic pricing offers benefits for charging electric vehicles (EVs), it's important to mention that this cost is liable to complete house billing, a hefty drawback



Figure 14: Stekker App

Implementing Personalization Features

Personalization features are implemented through software that communicates with the Charger. The software sends commands to these components to adjust the charging current according to the user's preferences.

User Profiles

Users can set up profiles that define their preferred charging current, start and end times, and other parameters. The system stores these profiles and applies the settings automatically when the user starts a charging session.

Safety and Reliability

Safety is paramount in EV charging systems. The interface includes features such as

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overcurrent protection and real-time monitoring to prevent any unsafe conditions during charging.

Phase 3: Different Approaches to Implementing Smart Charging

Having explained the key concepts associated with smart charging, this section will now outline different approaches to implementing smart charging. As previously noted, smart charging aims to enhance the effectiveness of electric vehicle (EV) charging sessions by optimizing either the rate or timing of charging. These methods can vary widely in complexity, from simple manual interventions like selecting optimal charging times to more advanced solutions that digitally connect EVs with the network for automatically adaptive charging sessions. This phase will then provide a detailed examination of the main smart charging methodologies. Federated learning-based systems for EV charging leverage collective data for personalized strategies, maintaining user privacy while optimizing the charging experience [13].

Simple Scheduled Charging

Scheduled charging is a popular method for "smart" charging. Although it doesn't use real-time data, it allows users to delay charging to a specific time, optimizing the timing. Users can either plug in the charger later or use the car's interface or a charging app to set a delay. Typically, scheduled charging is used to save money by taking advantage of lower energy prices during off-peak hours, especially when Variable Rate Tariffs are in effect.

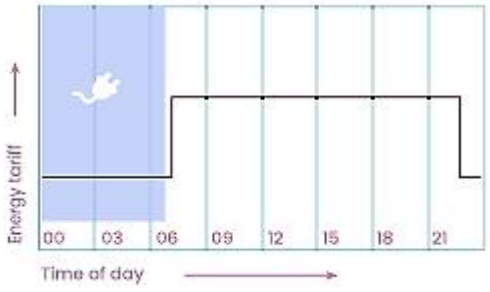


Figure 15: Charging Schedule

Advanced Smart Charging Management

The concept of Smart Charging Management involves using smart battery chargers that adjust their current based on the overall home current to prevent overloading the main switch breaker. This avoids overloading of the grid.

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Dynamic Pricing Models

Dynamic pricing models adjust electricity prices based on real-time supply and demand conditions. These models encourage users to shift their energy consumption to times of lower demand, helping to reduce grid congestion and optimize energy usage.

Time-of-Use (TOU) Pricing

Time-of-Use (TOU) pricing sets different electricity rates for various times of the day, usually with lower rates during off-peak hours and higher rates during peak hours. Utilities implement TOU pricing by installing smart meters that record energy consumption in real-time, allowing customers to be billed based on these time-specific rates.

Real-Time Pricing (RTP)

Real-Time Pricing (RTP) adjusts electricity prices based on current market conditions. Prices can fluctuate throughout the day, reflecting changes in energy supply and demand. Like Time-of-Use (TOU) pricing, RTP requires smart meters and advanced metering infrastructure (AMI) to track real-time energy consumption. Customers are then billed according to these real-time rates.

Benefits of Dynamic Pricing

- **Cost Savings**: Customers can reduce their electricity bills by shifting their energy usage to off-peak periods with lower rates.
- **Grid Optimization**: Dynamic pricing helps balance the load on the grid, reducing the need for expensive peak generation and minimizing the risk of blackouts.
- **Environmental Impact**: By encouraging off-peak energy usage, dynamic pricing supports the integration of renewable energy sources and reduces reliance on fossil fuels. Dynamic pricing strategies align with user behavior, enabling a personalized and cost-effective charging experience that adapts to real-time grid demand [11].

Integration of Artificial Intelligence (AI) for Predictive Analytics

AI and machine learning techniques can enhance smart charging systems by providing predictive analytics to optimize charging schedules and energy usage.

Predictive Analytics

- **Data Collection**: AI systems collect data from various sources, including EV usage patterns, grid conditions, weather forecasts, and energy prices.

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- **Machine Learning Models**: Machine learning algorithms analyze the collected data to identify patterns and make predictions about future energy demand and supply. Machine learning-based optimization for EV charging predicts user behavior and adapts charging patterns, enhancing both user satisfaction and grid efficiency [10].

- **Optimization**: Based on these predictions, AI systems optimize charging schedules to ensure efficient energy usage, cost savings, and grid stability. User-centric EV charging control enhances grid stability while adapting to individual user needs, ensuring a balanced and personalized charging process[12].

AI Applications in Smart Charging

- **Demand Forecasting**: AI models predict future energy demand based on historical data and current conditions, allowing for proactive grid management.

- **Load Balancing**: AI systems dynamically adjust charging rates and schedules to balance the load on the grid, preventing congestion and ensuring stable operation. Personalized charging strategies tailored to user preferences and grid constraints enhance the overall efficiency and convenience of EV charging systems [6]

- **User Preferences**: AI can personalize charging schedules based on individual user preferences, ensuring that EVs are charged in the most convenient and cost-effective manner.

The Roadmap

Building on the discussed trends and Pakistan's goal of a fossil-free future, three strategic horizons are outlined:

1. **Promoting Enhanced Energy Consumption Practices:** The first horizon focuses on educating people about Variable Rate Tariffs (VRT). This involves encouraging the use of energy during optimal hours to benefit both the electricity network and reduce energy costs.

2. **Maximizing Solar Power Utilization**: The second horizon aims to capitalize on solar power. Since many EV drivers with home chargers also have solar panels, there is a significant opportunity to use the solar energy they generate more efficiently.

3. **Reducing Grid Energy Losses and Enhancing the Distribution Network**: The third horizon envisions a future where Pakistan aims to minimize grid energy losses and improve the distribution network. Effective management strategies, such as user-centric

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adaptive charging, help mitigate the impact of EV charging on electrical distribution networks, enhancing both efficiency and user satisfaction [4]. In this scenario, EV users play a crucial role by enabling home charging, which fosters greater self-sufficiency in energy consumption.

Challenges and Future Research Directions

Challenges:

One major challenge in charging light electric vehicles (LEVs) is its impact on the quality of the AC grid. Charging multiple LEVs from residential connections can negatively affect the grid's voltage and current quality. Another challenge is ensuring fast and efficient charging since most LEVs take hours to reach a full charge.

Future Trends:

Future research should concentrate on developing new DC-DC converter designs that improve charging efficiency and reduce charging time. Another promising area is integrating renewable energy sources, like solar photovoltaic (PV) systems, into LEV charging infrastructure. Integrating EVs into power systems requires user-centric charging strategies to balance user needs with grid demands, enhancing overall system performance[23]. Additionally, exploring wireless power transfer (WPT) for LEV charging could offer a safer and more convenient solution.

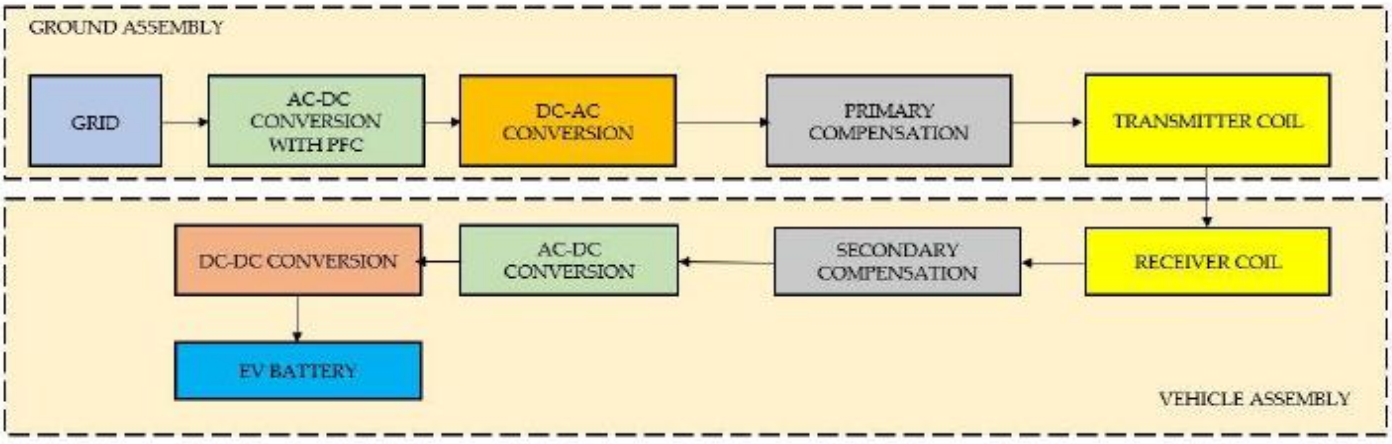


Figure 16: Wireless Charging

The research and development of user-centric adaptive charging systems for EVs is an ongoing process. Future work may include:

- **Integration with Renewable Energy Sources**: Enhancing the integration of renewable

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energy sources such as solar and wind power with adaptive charging systems to maximize the use of clean energy.

- **Advanced Control Algorithms**: Developing advanced control algorithms that can dynamically adjust charging parameters based on real-time grid conditions, user preferences, and renewable energy availability. Genetic algorithm-based approaches optimize EV charging by focusing on user needs, ensuring that the charging process is both efficient and personalized [8]

- **User Behavior Analysis**: Conducting comprehensive studies on user behavior and preferences to further refine personalized charging strategies and improve user satisfaction.

- **Scalability and Deployment**: Exploring the scalability of adaptive charging systems for large-scale deployment in urban and rural areas, considering infrastructure limitations and cost implications.

- **Cybersecurity and Data Privacy**: Addressing cybersecurity and data privacy concerns associated with user-centric adaptive charging systems to ensure secure and reliable operation.

Conclusion

To provide insights into the average annual kilometers driven by EVs, estimates can be made. By assuming an average of these figures and considering the percentage of at-home charging sessions, we can calculate the total megawatts (MW) required for charging EVs. Additionally, amid a global energy crisis, increased awareness of rising energy prices has prompted consumers to seek ways to save energy. Given the high cost of electricity, EV users are likely to adopt new methods to reduce their electricity bills. In conclusion, the development of chargers for user-centric adaptive charging systems represents a significant advancement in electric vehicle (EV) technology. By integrating power electronics with innovative sensing and control mechanisms, these systems enable personalized charging experiences that cater to the unique preferences and needs of individual EV drivers. Furthermore, the shift towards user-centric charging infrastructure reflects a concerted effort to enhance the overall EV ownership experience and facilitate the transition to sustainable transportation. As the demand for EVs continues to grow, the development of adaptive charging solutions demonstrates a commitment to meeting the evolving needs of consumers while advancing towards a

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greener, more sustainable future.

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