Innovative Solutions for Electric Vehicle Charging Infrastructure

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ABSTRACT

The rising adoption of electric vehicles (EVs) necessitates the development of adequate and efficient charging system infrastructure. A key component of this infrastructure is the electric vehicle (EV) battery charging system. This research focuses on designing a charging system infrastructure for EVs utilizing a DC to DC converter. The system is engineered to prioritize safety, efficiency, and compatibility with a variety of EV models. It is capable of delivering output voltages ranging from 12 volts to over 60 volts, sufficient for charging EV batteries. Performance evaluation was conducted through correlation analysis simulations using MATLAB and experimental testing. The system demonstrates the ability to charge batteries with voltage variations from 12 to 60 volts, commonly required by electric vehicles. The correlation analysis results indicate a relationship between charging current and charging time, showing that higher charging currents reduce charging durations. Additionally, attention must be given to battery temperature during charging to prevent overheating, which can damage battery cells.

Keywords: Electric Vehicle, Battery Charger, Dc to Dc Converter, Efisiensi

Introduction

The transition to electric vehicles (EVs) represents a critical step in mitigating the effects of climate change and addressing issues of local air pollution. With the growing recognition of the environmental and economic benefits, EV adoption has accelerated, supported by advancements in lithium-ion (Li-ion) battery technology. However, despite efforts by manufacturers to introduce electrification across their product lines, battery electric vehicles (BEVs) without internal combustion engine (ICE) support still face challenges in achieving widespread consumer acceptance. Key barriers include concerns over limited range and longer charging durations compared to conventional gasoline refueling.

Electric vehicles offer a promising solution to reduce environmental impacts and dependency on finite fossil fuels. Their primary advantages, such as lower greenhouse gas emissions, improved energy efficiency, and reduced reliance on fossil energy sources, are becoming increasingly important as the global community seeks sustainable transportation alternatives. Nevertheless, the success of EVs largely depends on the development and deployment of robust charging infrastructure that ensures efficiency, reliability, and user convenience.

This study highlights the critical role of charging systems in supporting the rapid expansion of the EV market. It explores the challenges in charger system development, such as technical limitations, compatibility, and infrastructure scalability, alongside recent innovations in charging technologies, from residential solutions to ultra-fast public charging networks.

Additionally, this research identifies the key factors necessary for designing effective charging systems, including power delivery, charging efficiency, compatibility with diverse EV models, and adherence to standardized charging communication protocols. By addressing these aspects, the study aims to provide actionable insights into overcoming existing challenges in EV charging technology and infrastructure.

Ultimately, this research seeks to advance the understanding of how charger systems influence the growth of the EV ecosystem, proposing solutions to accelerate global adoption and transition toward a cleaner, more sustainable transportation future.

Literature Review

Electric Car

An electric car is a vehicle that uses one or more electric motors to drive the wheels and uses a battery as an energy source for the electric motor. As an alternative to conventional cars that use internal combustion engines that run on fossil fuels, electric cars are considered more environmentally friendly because they do not produce exhaust emissions when used.

Generally, electric cars have a more limited range compared to conventional cars, but developments in battery technology have made it possible to produce electric cars with increasing range. Some electric cars even have enough range to be used for daily activities without needing to be charged repeatedly. Charging an electric car can be done at home using a regular socket or special electric charging stations which are increasingly common in public places. In addition, some electric car models are also equipped with a fast charging feature which allows users to charge the battery in a shorter time.

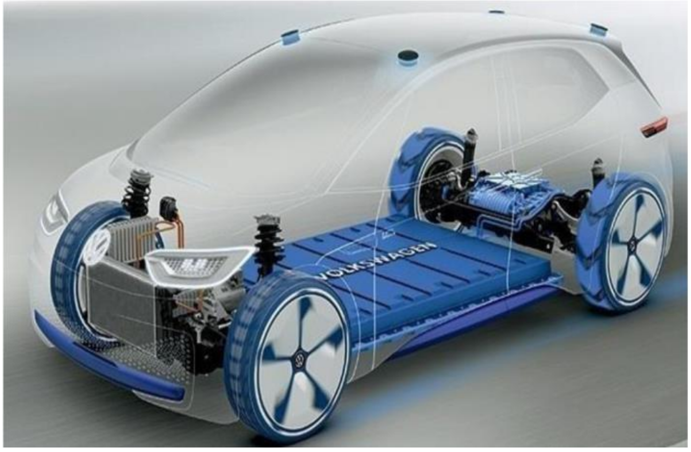

Figure 1. Electric Vehicles

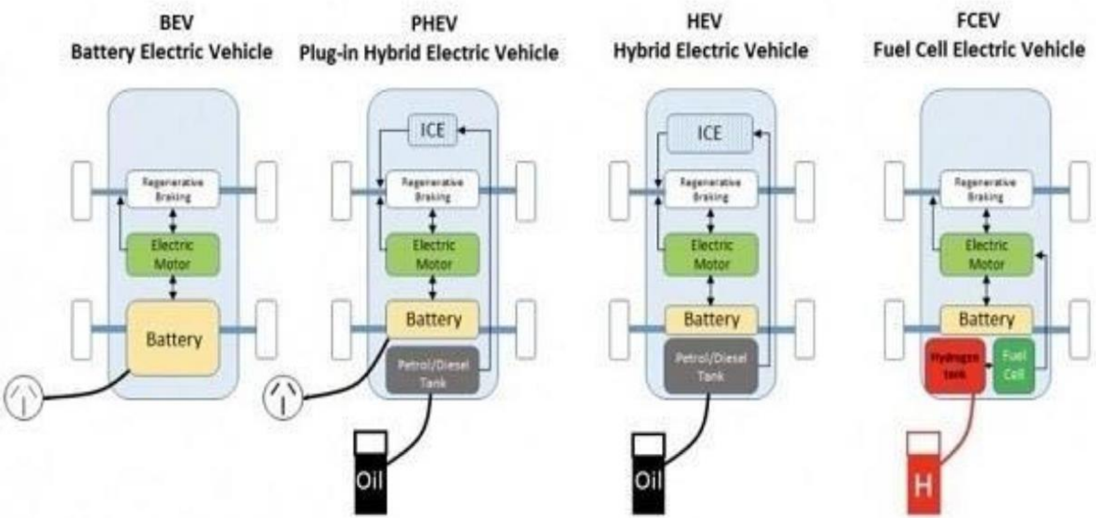

Figure 2. System Baterry Cell

Types of Electric Car Charging Power Sources

1. Alternating current (AC) charging

2. Slow charging (AC slow charging)
3. Fast charging (AC fast charging)
4. Inductive charging (AC inductive charging)
5. Direct current charging (DC charging)

The energy stored by the car battery remains DC electricity. The type of electricity source here is seen from the type of electricity that is "plugged" into the car's charging port via a plug from the source.

Charging Power.

Calculating the power of an electric car charging station requires knowing the type of phase, voltage and current. In station systems that use alternating current, it is also necessary to know the power factor (pf). Charging power can be roughly calculated using the following formula:

Alternating current (AC) charging

- Phase-one = V x I (VA) or V x I x pf (Watt) (2.1)
- Three-phase = $\sqrt{3}$ x V x I (VA) or 1.73 x V x I x pf (Watt) (2.2)

where V = voltage (volts),
I = current (amperes),
pf = power factor

Direct current (DC) charging

Charging power = V x I (VA/(Watt) (2.3)
where V = voltage (volts)
I = current (amperes)

Charging time (charging time)

Charging time can be roughly calculated by dividing the battery capacity by the power of the electric car charging station.

Charging time = Car Battery Capacity/Charger Capacity (charging station)

Example: For a Tesla, it is 85 kWh divided by 22 kW, which equals 3.9 hours.

Mileage (Range) The mileage range can be calculated by dividing the car battery capacity (kWH) by the electrical energy consumption (kWH) per kilometer. Please keep in mind that this is only a rough estimate.

The range of distance that is close to the actual depends on many factors, for example the operating mode and the use of electrical loads, such as AC. Mileage = Car Battery Capacity / Energy Consumption per km

Example: A car with an 85kWh battery, consumes 0.181kWH per km, then Mileage = 85 kWh / (0.181 kWh/km) = 469 km.

Research Methodology

Variable Operational Parameters

1. Independent Variable:
    a. Charging Technology: (a) AC Charging, (b) DC Charging, (c) Wireless Charging.
    b. Charging Power: (a) 7 kW, (b) 22 kW, (c) 50 kW, (d) 150 kW.
    c. Infrastructure Type: (a) Public Charging Station, (b) Home Charging (Wallbox), (c) Workplace Charging.
2. Dependent Variable:
    a. Charging Speed: The time required to charge a vehicle battery from zero to full in minutes.
    b. Energy Efficiency: The percentage of energy actually used to charge a battery compared to the total energy consumed during the charging process.

    c. Implementation Cost: The total cost to install and operate a particular charging system, including hardware, installation, and electricity costs.
3. Control Variables:
    a. Vehicle Battery Capacity: kWh.
    b. Vehicle Model: Determines battery characteristics and charging requirements.
    c. Operational Environment: Temperature, humidity, and other weather conditions that may affect charging system performance.
4. Contextual Variables:
    a. Geographic Location: Urban, suburban, or rural area.
    b. User Needs: Daily charging needs versus long distance charging.
    c. Infrastructure Availability: The number and type of charging stations available in the study area.

By defining clear operational parameters for these variables, research can be conducted in a more focused manner and can provide deeper insight into the factors that influence the efficiency and affordability of electric vehicle charging systems.

Population and Sample

1. Population:
    a. Population is all electric vehicles operating in a specific area (for example, a city, state, or country).
    b. It also includes all types of charging infrastructure available in the region, be it public charging stations, home charging, or workplace charging.
2. Sample:
    a. Samples from the population can be randomly selected to represent variations in electric vehicles and charging infrastructure.
    b. Example of sample settings:
        - 100 randomly selected electric vehicles from various makes and models.
        - 20 charging stations were randomly selected from different locations in the study area.
        - It is important to select a sample that is representative of the population as a whole to ensure the results of the study are widely applicable.

By using appropriate samples, research can provide significant insight into the effectiveness of various technologies and methods in improving the efficiency and affordability of electric vehicle charging systems, as well as provide more detailed recommendations for future developments in the electric vehicle industry.

Data collection technique

1. Observation:
    a. Conduct direct observations of the electric vehicle charging process across various types of charging infrastructure to collect data on charging speed, energy efficiency and user experience.
    b. Observations can also be made of the charging infrastructure itself to check its physical condition, reliability and availability.
2. Interview:
    a. Conduct interviews with electric vehicle owners to understand their experiences using different charging systems, including the challenges they face and their expectations for improvements.
    b. Interviews can also be conducted with industry experts, policy makers, and other stakeholders to gain a broader perspective on related issues.

3. Questionnaire:

   a. Distribute questionnaires to electric vehicle owners and charging infrastructure operators to collect structured data on user preferences, charging needs, and perceptions of efficiency and costs.
   b. The questionnaire may include questions regarding expected charging speeds, preferences regarding charging technology, and perceived affordability levels.
4. Measurement and Testing:
   a. Perform direct measurements of charging time, energy efficiency and charging system performance using specialized measuring tools and software.
   b. Field testing can also be carried out to validate simulation results and test the performance of the charging system under various environmental conditions.
5. Document Analysis:
   a. Collect and analyze data from literature, industry reports, technical standards, and other documents to gain a deeper understanding of the latest developments in electric vehicle charging technology and market trends.

   By using this combination of data collection techniques, research can produce comprehensive and relevant data to support analysis and findings about the efficiency and affordability of electric vehicle charging systems.

   Correlation Data Analysis Method:
   1.) Perform correlation analysis to evaluate the relationship between certain variables, such as the relationship between charging speed and charging power, or the relationship between implementation costs and energy efficiency.
   2.) Pearson or Spearman correlation may be used depending on the characteristics of the data.

By using this data analysis method, research will gain a comprehensive understanding of the efficiency and affordability of electric vehicle charging systems and the factors that influence them.

Results

A DC-DC converter

DC to DC converter is an electronic circuit whose function is to change the direct voltage (DC) level from the input source into the desired output direct voltage (DC) level.

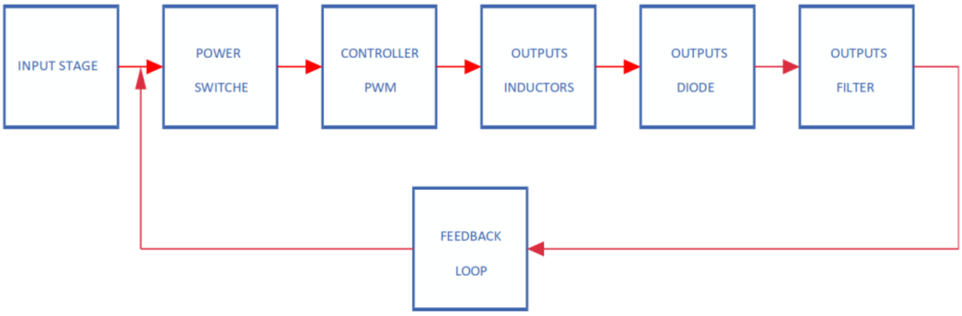

Figure 3. Dc To Dc Converter Block Diagram

This circuit can flow a maximum current of 15 amperes at a voltage of 66 volts. With such a large voltage and current range, it is sufficient as an electric vehicle battery charger for slow charging.

Circuit Testing

Before using it to charge the battery, measurements and settings are first carried out in several parts of the circuit, so that a voltage level is obtained according to the voltage of the battery to be charged, as in the picture below.

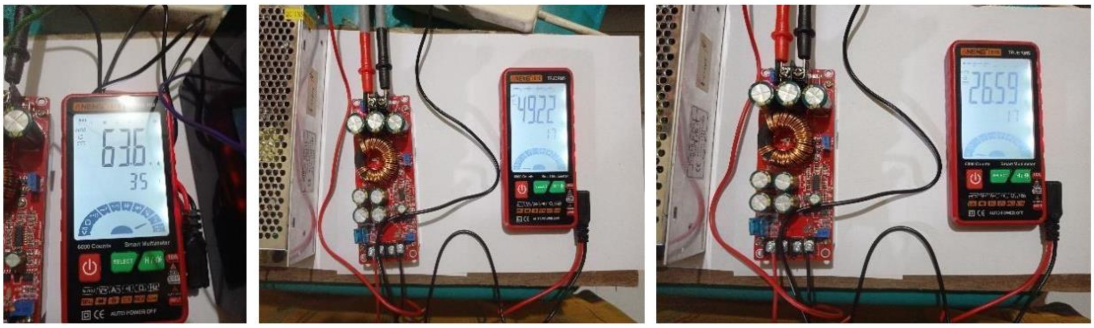

Figure 4. Voltage Levels for Each Battery Voltage (A) for 60 Volt Batteries, (B) for 48 Volt Batteries and (C) for 24 Volt Batteries

In the picture above you can see that this system can charge batteries from 60 volts to 12 volts, by adjusting the output voltage via the trimpot (CV V adj) which is near the output terminal. Next, after selecting the voltage according to the battery used, the battery is charged. In this research, a 12 Volt, 7.2 Ah lead acid battery was used.

From the results of the tests that have been carried out, the following table can be created:

Table 1. Charging Test Results on 12V, 7.2Ah Batteries

No	Time	Voltage (V)	Current (A)	Temperature (0C)
1	21:27	10.26	0.5	27
2	21:28	10.28	0.8	28
3	21:29	10.28	1,2	28
4	21:30	10.15	1,2	28
5	21:31	10,12	1.3	28
6	21:32	10.14	1.35	29
7	21:33	10,11	1.35	29
8	21:34	10,12	1.38	31
9	21:35	11.08	1.55	31
10	21:36	11.07	1.58	32
11	21:37	11.03	1.72	32
12	21:38	11.03	1.87	33
13	21:39	11.01	2.05	34
14	21:40	17.03	2.07	34
15	21:41	12.39	2.09	35
16	21:42	12.37	2.11	36
17	21:43	12.35	2.42	36
18	21:44	12.37	2.12	37
19	21:45	12.32	2.41	38
20	21:46	12.41	2.21	38

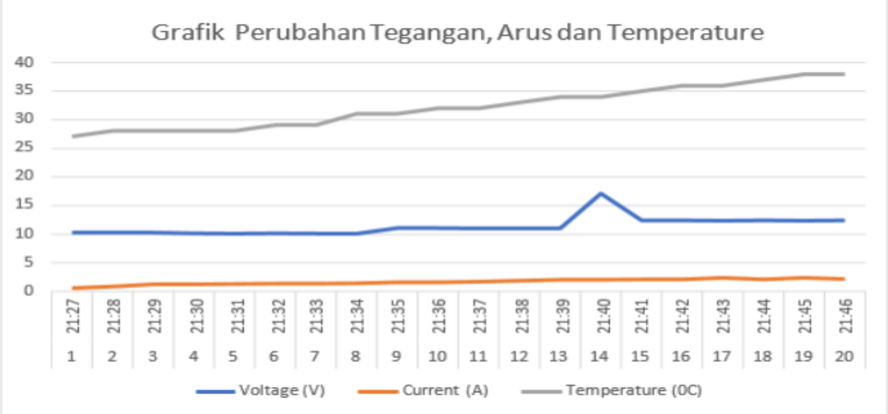

Figure 5. Graph of Changes in Voltage, Current and Temperature in the Battery

Correlation Analysis

In this research, a correlation analysis was carried out between charging current and charging speed. The simulation is carried out with MATLAB and the simulation graph shows the correlation between charging current and battery charging speed

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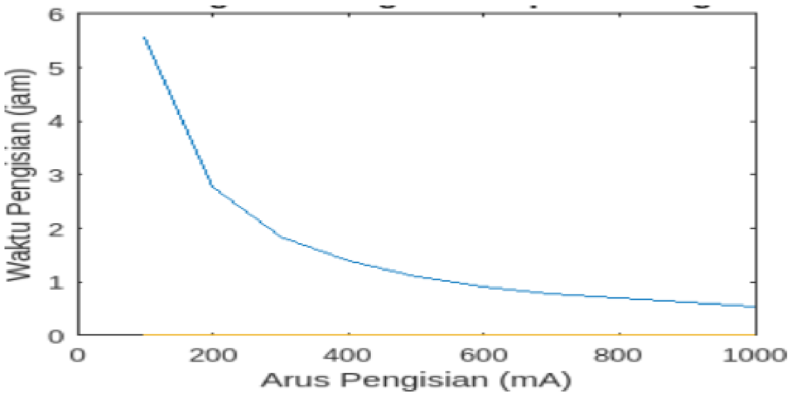

Figure 6. Correlation graph between charging current and battery charging speed, Matlab results

Conclusion

The dc to dc converter circuit for charging electric vehicle batteries has been successfully created and works as expected. This circuit can charge batteries with voltage variations from 12 volts to 60 volts which are widely used in electric vehicles. The results of correlation analysis show that there is a correlation between charging current and charging time. Where the greater the charging current, the faster the charging time

References

[1] Callegaro, Leonardo, et al. "A simple smooth transition technique for the noninverting buck–boost converter." IEEE Transactions on Power Electronics 33.6 (2017): 4906-4915.

[2] Chen, Bo-Yuan, and Yen-Shin Lai. "New digital-controlled technique for battery charger with constant current and voltage control without current feedback." IEEE transactions on industrial electronics 59.3 (2011): 1545-1553.

[3] Hamdani, Hamdani, et al. "Design of a Modified Sine Wave Inverter in a Solar Power Plant for Residential Homes." UISU National Engineering Seminar (SEMNASTEK). Vol. 3.No. 1. 2020.

[4] Kheraluwala, MN, et al. "Performance characterization of a high-power dual active bridge DC-to-DC converter." IEEE Transactions on industrial applications 28.6 (1992): 1294-1301.

[5] Oh, Chang-Yeol, et al. "A High-Efficient Nonisolated Single-Stage On-Board Battery Charger for Electric Vehicles." IEEE transactions on Power Electronics 28.12 (2013): 5746- 5757.

[6] Qu, Xiaohui, et al. "Hybrid IPT Topologies with Constant Current or Constant Voltage Output for Battery Charging Applications." IEEE Transactions on Power Electronics 30.11 (2015): 6329-6337.

[7] Suhendra, Irfan, Angga Rudinar, and Muhammad Ary Murti. "Design and Implementation of an Automatic Battery Charging System for IoT-Based Electric Cars." eProceedings of Engineering 6.2 (2019).

[8] Sujitha, N., and S. Krithiga. "RES based EV battery charging system: A review." Renewable and Sustainable Energy Reviews 75 (2017): 978-988.

[9] Tan, Kang Miao, Vigna K. Ramachandaramurthy, and Jia Ying Yong. "Bidirectional Battery Charger for Electric Vehicles." 2014 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA). IEEE, 2014.

[10] Tar, Bora, and Ayman Fayed. "An overview of the fundamentals of battery chargers." 2016 IEEE 59th International Midwest Symposium on Circuits and Systems (MWSCAS). IEEE, 2016.

[11] Tashakor, Nima, Ebrahim Farjah, and Teymoor Ghanbari. "A bidirectional battery charger with modular integrated charge equalization circuit." IEEE Transactions on Power Electronics 32.3 (2016): 2133-2145.

[12] Tharo, Zuraidah, and M. Alfi Syahri. "Combination of solar and wind power to create cheap and eco-friendly energy." IOP Conference Series: Materials Science and Engineering. Vol. 725. No. 1. IOP Publishing, 2020.

[13] Veerachary, Mummadi, and Malay Ranjan Khuntia. "Design and analysis of two-switch-based enhanced gain buck–boost converters." IEEE Transactions on Industrial Electronics 69.4 (2021): 3577-3587.

[14] Wu, Hao, et al. "An Optimization Model for Electric Vehicle Battery Charging at A Battery Swapping Station." IEEE Transactions on Vehicular Technology 67.2 (2017): 881-895.

[15] Yilmaz, Murat, and Philip T. Krein. "Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles." IEEE transactions on Power Electronics 28.5 (2012): 2151-2169.