Atomic Spectroscopy

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Enhancing Safety and Accelerating Charging at Electric Vehicles Charging Stations

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ABSTRACT: As the world moves closer to sustainability and electric vehicles adoption, it is very important for EV charging stations to operate as secure and efficient as possible. This paper states usual safety issues that come out from the use of EV chargers based on real life experience, such as electrical risks and user behavior. It also discusses methods to reduce these risks such as implementing safety standards, improved electrical safety precautions, fire suppression systems and user education programs. Simultaneously, this paper includes a designed model of a DC fast charger to accelerate the charging procedure, solving the issue of charging duration, which is one of the critical struggles that EV owners face. Using MATLAB-Simulink, it evaluates a range of charging solutions: such as fast chargers, and ultra-fast chargers. The aim of this paper is to result in a complete framework that plays a big part in sustainable expansion of electric transportation, by integrating safety advancements and effective charging options at once. To sum it up, this research focuses on safety enhancement and accelerating charging in EV chargers

Keywords: Electric Vehicles EV, Solar PV, Hybrid Energy, Charging Station.

INTRODUCTION

INTRODUCTION TO ELECTRIC VEHICLES CHARGING STATION

The history of Electric Vehicle (EV) charging stations traces back to the early days of electric vehicles themselves. While the concept of electric cars dates as far back as the 19th century. The first electric car was invented by Gustave Truves as shown in Figure-1. It was only in the latter half of the 20th century that the need for a dedicated charging infrastructure began to emerge. Initial charging setups are primarily designed for experimental or limited-use electric vehicles. The late 20th century witnessed sporadic development of public charging stations, especially in regions with heightened environmental concerns. However, it was not until the early 21st century, with advancements in battery technology and a renewed global focus on sustainable transportation, that the proliferation of EVs and the corresponding expansion of charging infrastructure gained significant momentum. Governments, businesses, and energy companies began investing heavily in the distribution of charging networks, ranging from residential chargers to fast-charging stations along major highways, to address range anxiety and facilitate the widespread adoption of electric vehicles. The history of EV charging stations thus is tied to the evolution of electric mobility, reflecting a dynamic interplay between technological innovation, environmental imperatives, and societal shifts toward sustainable transportation solutions and towards reducing power generation from fossil fuel [1] and hence reducing the problems of power transmission lines [2]

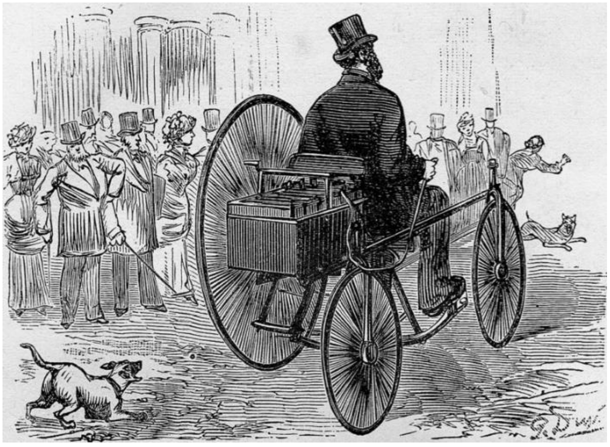

Figure-1: Gustave Trouvé's Tricycle (1881), World's First Electric Car

The urgent need to slow down climate change and switch ourselves away from fossil fuels has caused a paradigm shift in the global transportation sector in favor of sustainable practices in recent years. The widespread use of electric vehicles (EVs), which provide a greener and cleaner alternative to traditional cars of internal combustion engine, is very essential in this revolutionary process, Figure-2 shows an EV model invented by Tesla. The infrastructure for Electric Vehicle Charging Stations (EVCS) is developing and expanding rapidly to support the EV market's growth.

Figure -1: Tesla Model 3 – 2019

TYPES OF EV CHARGING CONNECTORSS

Electric vehicle (EV) charger connector types vary, catering to different charging speeds, power levels, and compatibility standards. Each connector type serves as a crucial interface between EVs and charging stations, facilitating the efficient transfer of electricity to recharge EV batteries. Some of the types are:

AC Type 1: Figure-3, shows a single-phase plug, common to electric vehicles (EVs) from Asia and America. Allows cars to charge at a speed of up to 7.4 kW, based on grid capacity and the car's charging capabilities. Some compatible EVs: Nissan Leaf (first-generation models), Mitsubishi i-MiEV, Kia Soul EV (first-generation models), Ford Focus Electric (first-generation models) **Error! Reference source not found.**3].

Figure-3: AC Plug Type 1

AC Type 2: Figure-4, shows a triple-phase connections, which let three more wires carry power. They are therefore able to charge cars faster. Depending on the capacity of the grid and the charging power of the vehicle, the maximum charging power at home is 22 kW, while the maximum charging power at public charging stations is 43 kW. Some compatible EVs: Nissan Leaf, BMW i3, Volkswagen e-Golf, Audi e-tron, Tesla Model S [3].

Figure-4: AC Plug Type 2

CHAdeMO: This type was developed in Japan (as shown in Figure-5), this rapid charging technology enables bidirectional charging in addition to extremely high charging capabilities. Asian automakers are now setting the standard for CHAdeMO-compatible electric vehicle offerings. It allows charging up to 100 kW. Some compatible EVs: Mitsubishi Outlander PHEV, Kia Soul EV (first generation), Honda Clarity Electric (with optional CHAdeMO adapter) [3].

Figure-5: CHAdeMO Plug

CCS: Figure-6, shows the CCS plug is an enhanced version of the type 2 plug, which has two extra power connections for rapid charging. Both AC and DC charging are supported, and charging at a maximum speed of 350 kW is possible. Compatible EVs include popular models from Audi, BMW, Ford, Hyundai, Jaguar, Kia, Mercedes-Benz [3].

Figure-6: CCS Plug

LEVEL OF PUBLIC CHARGING AND CHARGING MODES

Level of Public Charging: The charging specifications are summarized in Figure-7, where the meaning of levels are as follows:

- Level 1 Public Chargers (Slow): It is a 120V standard wall outlet. It takes tens of hours to fully charge an electric vehicle and is the slowest charging level.
- Level 2 Public Chargers (Fast): It is the typical EV plug found in homes and garages. The majority of public charging stations are level 2.
- Level 3 Public Chargers (Rapid): Level 3 chargers that are also known as DCFC or DC Fast Chargers, are found in certain public stations. The quickest way to charge a car is via one of these charging stations. Note that not all electric vehicles are compatible with this level of chargers.

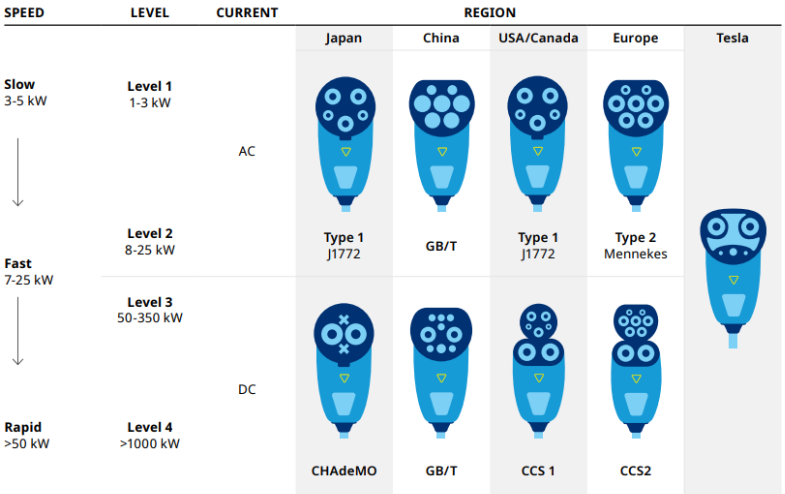

Figure-7: Charging Specifications

Charging Modes: There are four different charging modes that are specified by the IEC 61851 standard as shown in Figure-8. [4]

- Mode 1: EV charges from household socket outlet, however, communication is required between the EVSE and the EV.

- Mode 2: uses a particular type of charging cable equipped with an in-cable control and protection device (IC-CPD). The inbuilt protection and ability to prevent overcharging ensures safe charging process and efficiency. The maximum current of this mode is 32A (250V single-phase or 480V three-phase).
- Mode 3: utilizes an EVSE that communicates with the vehicle to negotiate the charging parameters, such as charging speed and time and can also provide feedback on the charging process.
- Mode 4: also known as DC fast charging, bypassing the onboard charger, uses a high-power charger that directly provides DC power to the vehicle's battery. It can provide 600 V DC with a maximum current of 400 A and demands a higher level of communication and stricter safety features. It can charge an EV up to 80% in as little as 30 minutes.

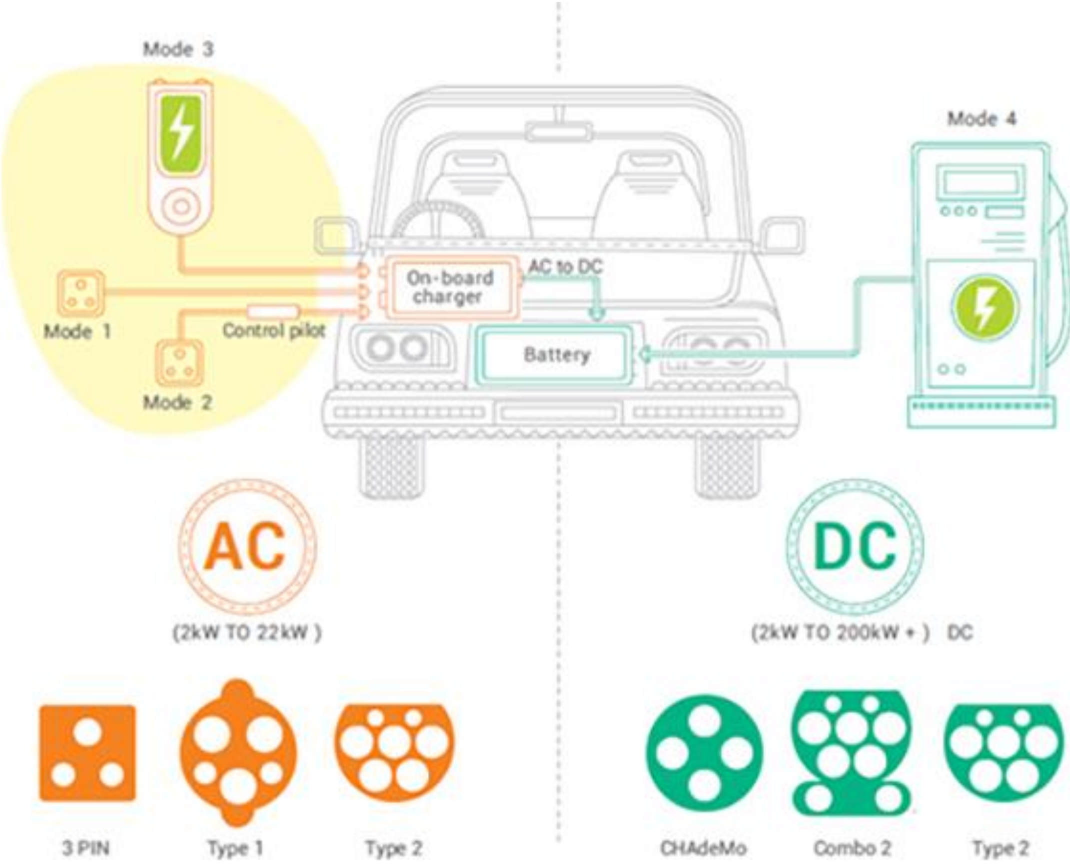

Figure-8: EV Charging Modes [4]

SAFETY STANDARDS OF EV CHARGING STATION

The guidelines and instructions referred to as EV charging standards are to ensure that the charging process is applied in a compatible and safe manner. These laws include electrical standards, grounding restrictions, and other safety precautions to guarantee the acceptance and growth of electric vehicles. Regulations for EV chargers (sometimes referred to as electric vehicle supply equipment or EVSE), vary from country to country and are determined by several factors such as the characteristics of the electrical grid and the kinds of EVs that are currently in the market. All the physical connectors, electrical parameters, and communication protocols that control the connection between the EV and the EVSE are governed by charging standards.

a) Charging standards: International organizations have developed charging standards, some of them are: International Electrotechnical Commission (IEC), Society of Automotive Engineers (SAE), ISO, Open Charge Point Protocol (OCPP), and the Open Charge Point Interface (OCPI). [5]

International Electro-technical Commission (IEC):
IEC 61851-1 is a standard for AC charging that covers the physical connection between the EV and the charging station and communication protocols between the two.
IEC 61851-23 is a standard for DC fast charging that also covers the physical connection between the EV and the charging station and communication protocols.
IEC 62196 is standard for AC and DC charging, covering the charging connector and communication protocols.

Society of Automotive Engineers (SAE):
SAE J1772: controls the charging connector (also known as the "J1772 plug") and the exchange of data between the electric vehicle and the charging station for Levels 1 and 2 of AC charging. From portable devices that can connect to a regular 120-volt outlet to home and public charging stations with higher power levels, the standard allows a range of single-phase AC

charging rates. It comprises the following: plug type, plug size, plug shape, cord length, plug color, wattage, voltage, current type, current phase, and plug type.
SAE J3068: in contrast, covers DC fast charging, including specifications for the charging connector and communication protocols.

- Open Charge Point Protocol (OCPP): a universal communications standard that facilitates the compatibility of hardware and software from many suppliers, hence reducing the complexity of installing multiple EV charging stations from disparate suppliers.
- Open Charge Point Interface (OCPI): an open automated roaming protocol that links service providers and owners of EV charging stations, enabling the owners to accept drivers from outside their network at their stations.

b) Safety Standards: Adherence to standards facilitates regulatory compliance and streamlines the development, installation, and operation of EV charging infrastructure, contributing to the widespread adoption of electric vehicles and the transition to sustainable transportation ecosystems. These standards establish common technical specifications for charging equipment, connectors, and communication protocols, enabling seamless compatibility between different EV models and charging infrastructure.

The different areas that EV standards consist of include: [8]

- Electric vehicle and performance testing
- Electrical safety and functional safety testing
- Cybersecurity and software testing.

A group of standards developed by the International Organization of Standardization (ISO) include: ISO 26262, focuses on the safety of vehicles, including EVs. ISO 17409, developed to help minimalize shock hazards within high-voltage testing, however, in EV performance testing, some standards include ISO 12405, ISO 18243, and ISO 15118. The international Electrotechnical Commission (IEC) is an organization that develops standards internationally for anything electrical and electronic. For example, IEC 61851-1 specifies the general requirements and testing methods for electric vehicle (EV) charging systems as shown in Figure-9. IEC 61851 as shown in Table-1, is a standard that addresses electromagnetic compatibility (EMC) and electromagnetic interference (EMI) testing, ensuring that a company's systems are not susceptible to conducted emissions. ISO 15118 Road vehicles -- Vehicle to grid communication interface is a proposed international standard defining a vehicle to grid (V2G) communication interface for bi-directional charging/discharging of electric vehicles.

Mode	Diagram	Limits			Supply & Interface	RCD Protection	Applications	Notes
		Phases	Current	Voltage				
1	EV connected directly to AC grid	1φ	16A	250V	AC, non-dedicated	✗	electric bikes & scooters	Direct connection of vehicle to conventional electrical outlets. Not allowed in the US, Israel, and England; prohibited for public charging by Italy; restricted in Switzerland, Denmark, Norway, and Germany.
		3φ	16A	480V				
2	EV connected to AC grid through cable incorporating RCD protection	1φ	32A	250V	AC, non-dedicated	✓	"slow AC"	Requires control box between vehicle and electrical outlet incorporating RCD protection. Prohibited for public charging by Italy; restricted in US, Canada, Switzerland, Denmark, France, and Norway. Typical portable / "emergency" charger.
		3φ	32A	480V				
3	EVSE connected to AC grid, supplies EV using tethered cable or socket-outlet with bidirectional communication	1φ	32A	250V	AC, dedicated (IEC 62196-2)	✓	"slow and quick AC"	EVSE permanently connected to electrical grid; includes RCD protection and bidirectional (EVSE/EV) communication. Typical public AC charger installation. Tethered (cable permanently attached) & untethered (dedicated socket outlet only) configurations.
		3φ	32A	480V				
4	EVSE rectifies AC grid & supplies DC power to EV using tethered cable with bidirectional communication	–	200A	400V	DC, dedicated (IEC 62196-3)	✓	"fast DC"	Current conversion handled by EVSE, not EV.

Figure-9: IEC 61851-1 Charging Modes

Table-1: IEC 61851 Certifications and Applications [9]

Certifications	Applications
IEC 61851-1	This standard covers the general requirements for charging electric vehicles, including safety considerations.
IEC 61851-21	This standard specifically covers AC charging for electric vehicles and includes requirements for safety and compatibility with different vehicle types.
IEC 61851-22	This standard covers the requirements for a.c. Electric vehicle charging stations for conductive connection to an electric vehicle, with a.c. Supply voltages according to IEC 60038 up to 690 V.
IEC 61851-23	This standard covers DC charging for electric vehicles and includes safety, compatibility, and communication requirements between the charger and the car.
IEC 61851-24	Together with IEC 61851-23, this standard applies to digital communication between a DC EV supply equipment and an electric road vehicle (EV) for control of conductive DC power transfer, with a rated supply voltage of up to 1 000 V AC or up to 1 500 V DC and a rated output voltage up to 1 500 V DC.

The standard provides multiple use cases like secure communication, smart charging and the Plug & Charge feature used by some electric vehicle networks. IEC 62196 (as shown in Table-1): Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles is a series of international standards that define requirements and tests for plugs, socket-outlets, vehicle connectors and vehicle inlets for conductive charging of electric vehicles and is maintained by the technical subcommittee SC 23H "Plugs, Socket-outlets and Couplers for industrial and similar applications, and for Electric Vehicles" of the International Electrotechnical Commission (IEC). In addition, IEC 63110 is an international standard defining a protocol for the management of electric vehicles charging and discharging infrastructures, which is currently under development.

DESIGN OF SLOW-MEDIUM-FAST EV CHARGING STATION

This project aims to design a Fast DC Charger on MATLAB Simulink with a main goal to reduce charging times and ensuring safety. The block diagram in figure 4.1 shows an example of the proposed system, where the main energy supply is the utility grid, however, in the absence of utility, the diesel generator will supply energy to the station, utilizing power to the vehicles' chargers. In addition, the presence of the UPS system has a very important role, where in the event of a sudden power outage or generator failure, the UPS system kicks in to provide immediate backup power to ensure uninterrupted power supply to the station chargers. Management between operation is done through the power management system (PMS).

Power Source Control:

In order to ensure uninterrupted charging in an EV charging station, the management between power sources is very crucial. Figure-10, shows a flow chart of the proposed project, two main power sources are available: utility grid as main power source and diesel generator as backup. In addition, a UPS system is integrated in order to provide protection against power interruptions and fluctuations.

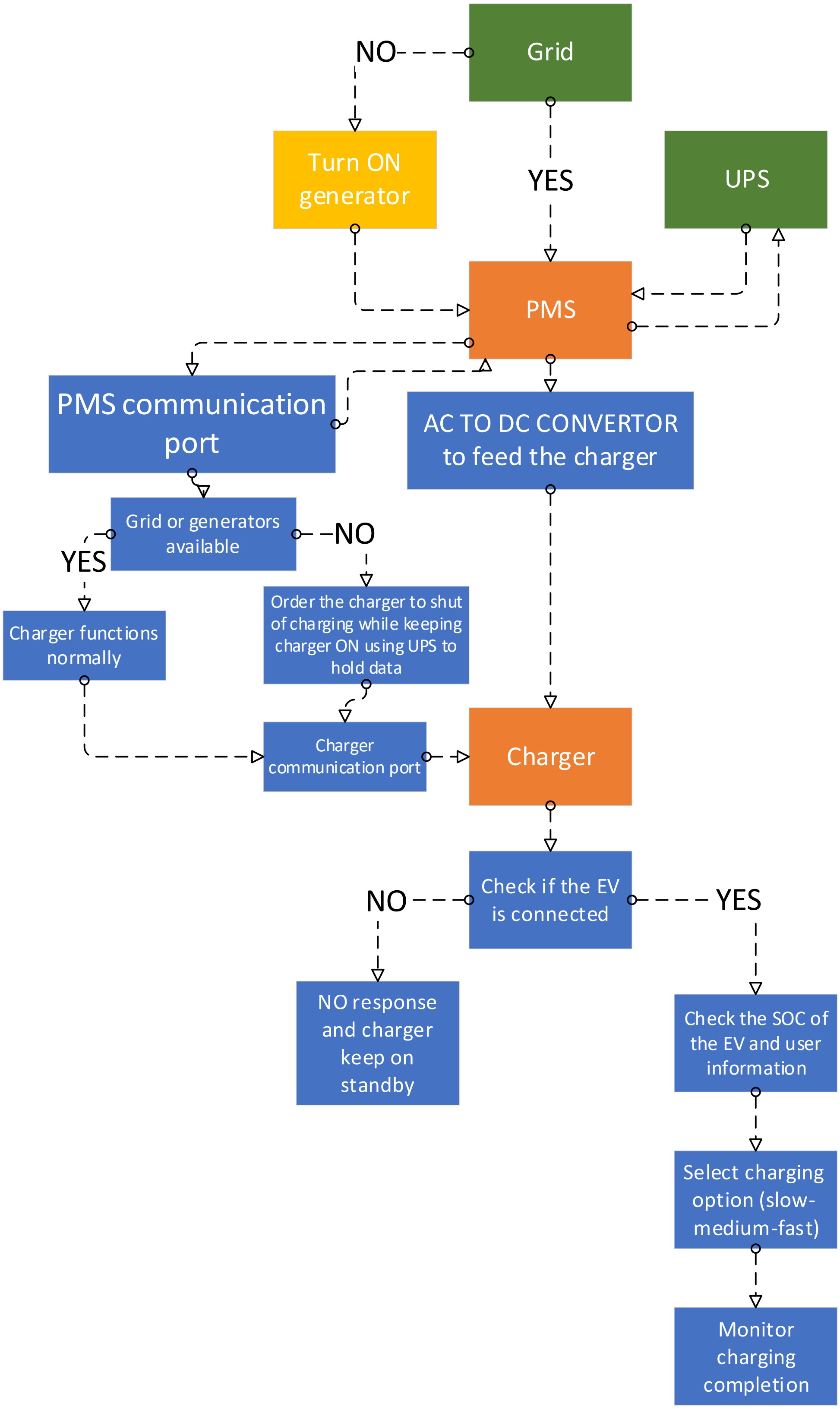

Figure-10: Flow Chart showing the General Mode of Operation of the EV Charging Station

A three-phase Automatic Transfer Switch (ATS) will be used as a central control unit to manage the power sources, connections between ATS, grid and generator are shown in Figure-11. Mode of operation: priority is given for the grid when available, and upon detecting an outage or significant voltage/frequency deviation, it will switch the power source to the diesel generator. The UPS system will provide immediate power backup during the transition period when switching between grid power and generator power, ensuring no interruption to the charging process.

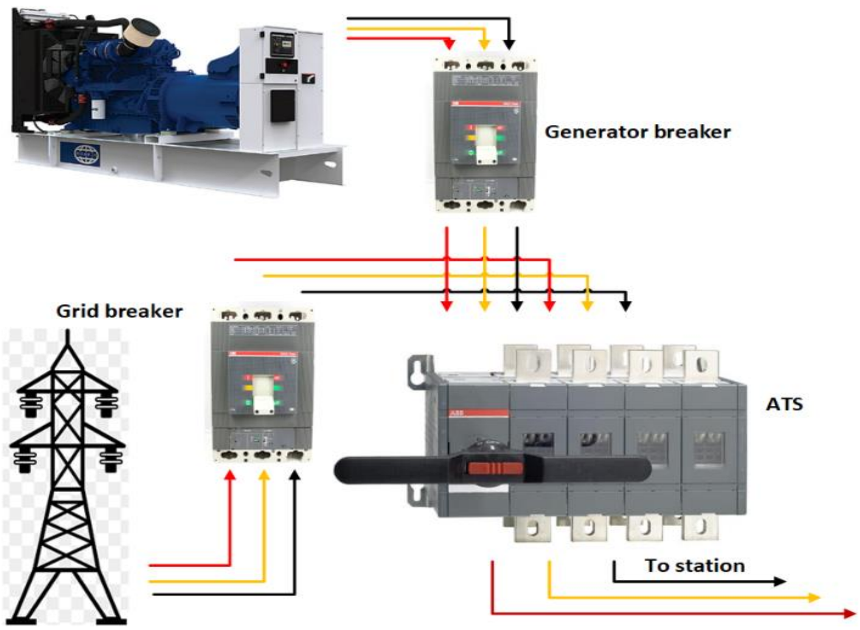

Figure-11: Connection between ATS, Grid and Generator

DC Fast Charger

DC fast chargers significantly reduce the charging time for electric vehicles by delivering high power directly to the battery. Figure-12 shows the design of a DC fast charger as implemented in MATLAB Simulink, it presents an efficient model to optimize performance and ensure reliability of EV chargers in real-world applications.

The model begins with a 3-phase power supply with 25kV voltage level, representing the grid power. Figure-13 and Figure-14 show the configuration and parameters of the three-phase transformer as implemented on MATLAB-Simulink. Three AC-DC converters that are shown in Figure-15, are combined to give an output power of 300kW and distributed as follow: CCS 175 kW and CCS 125 kW. Electric vehicles that support CCS connectors include: BMW, Jaguar, Honda, Kia, Nissan, Tesla etc.

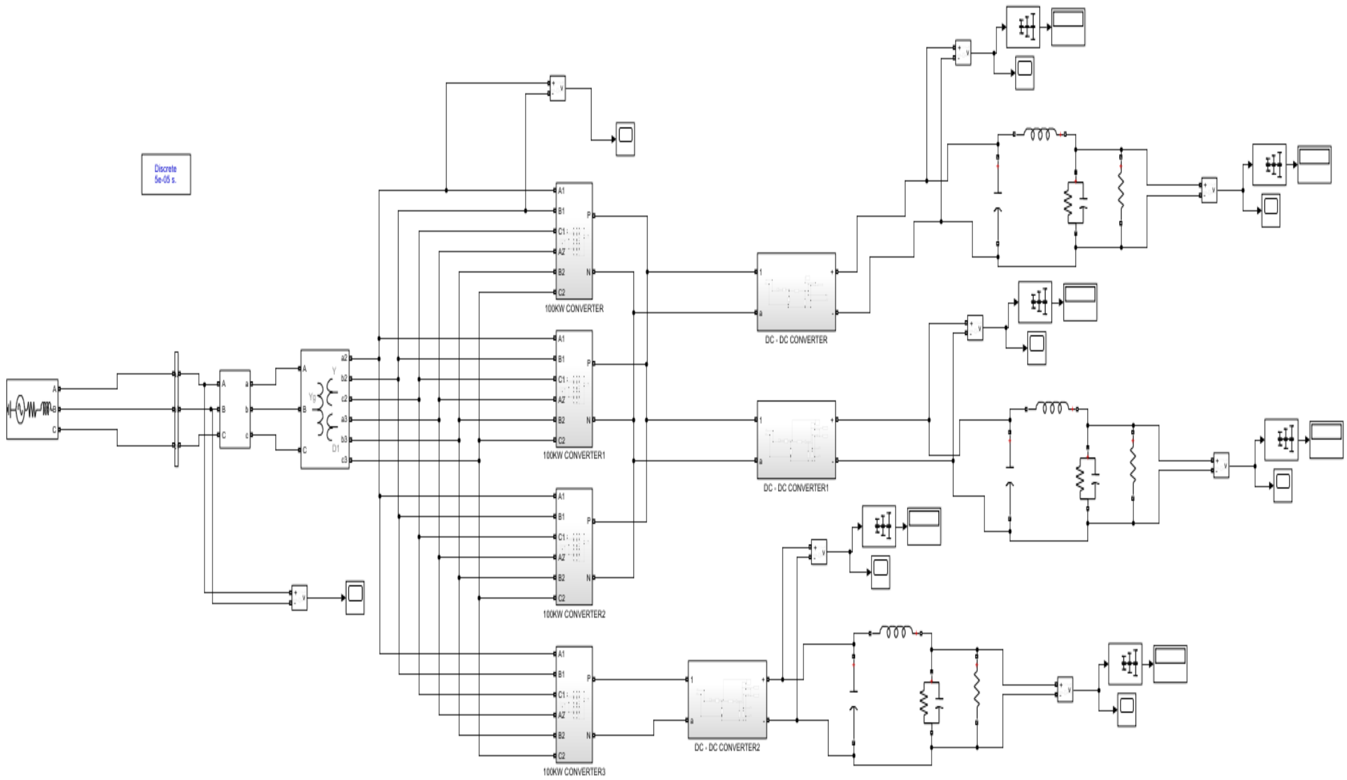

Figure-12: DC Fast Charger as implemented on MATLAB-Simulink

In addition, a separate 100 kW converter is included in the design, for a CHAdeMO connector which is supported by Nissan Leaf, Lexus UX 300e, Mitsubishi Outlander PHEV, Toyota Prius Plug-In, and Nissan e-NV200 etc.

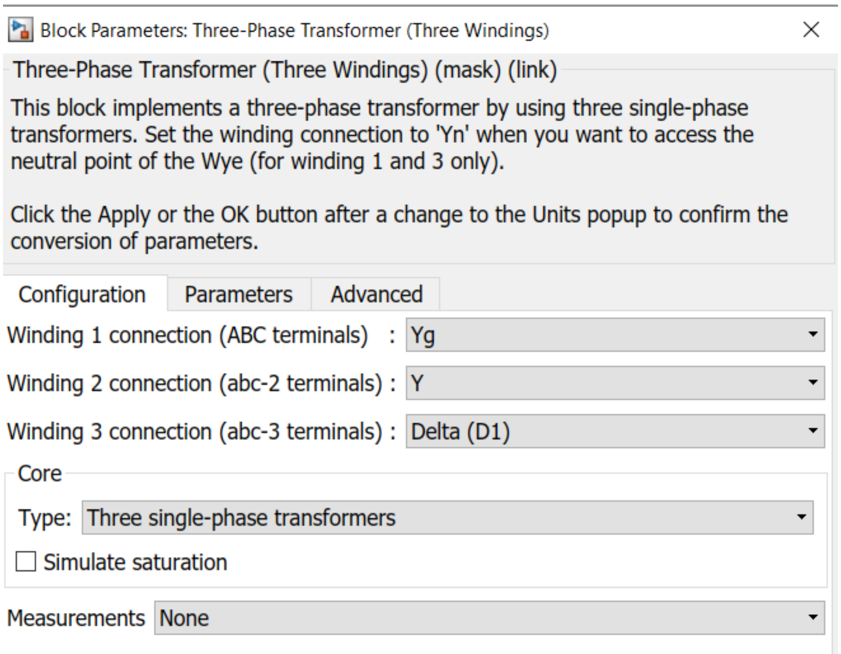

Figure-13: Three-Phase Transformer Configuration on MATLAB Simulink

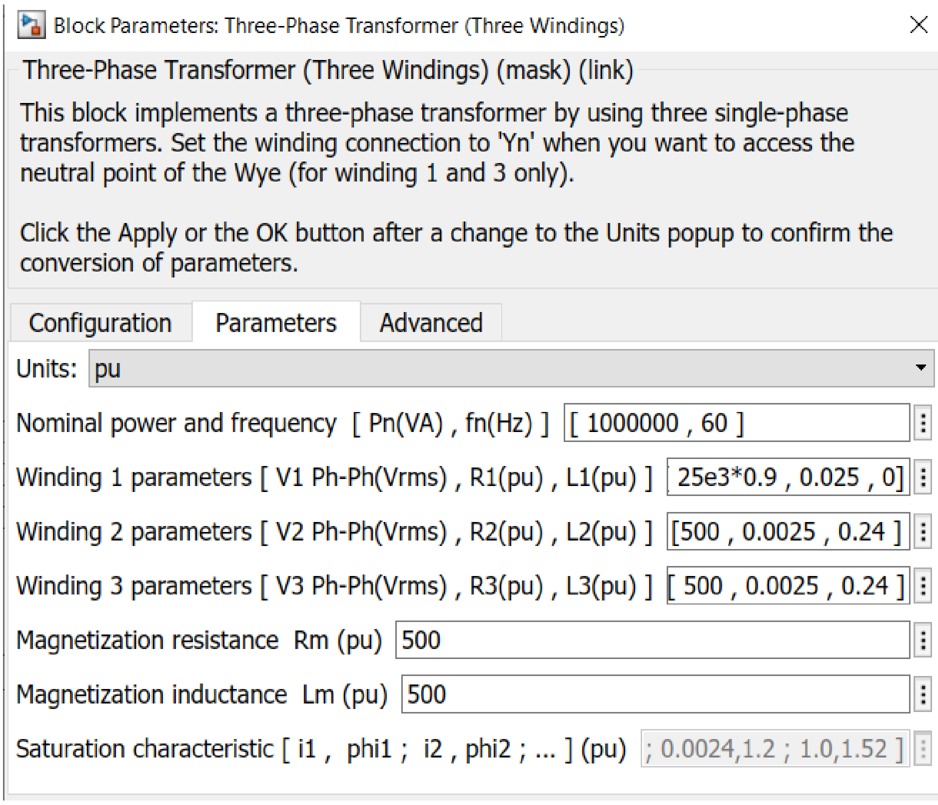

Figure-14: Three-Phase Transformer Parameters on MATLAB Simulink

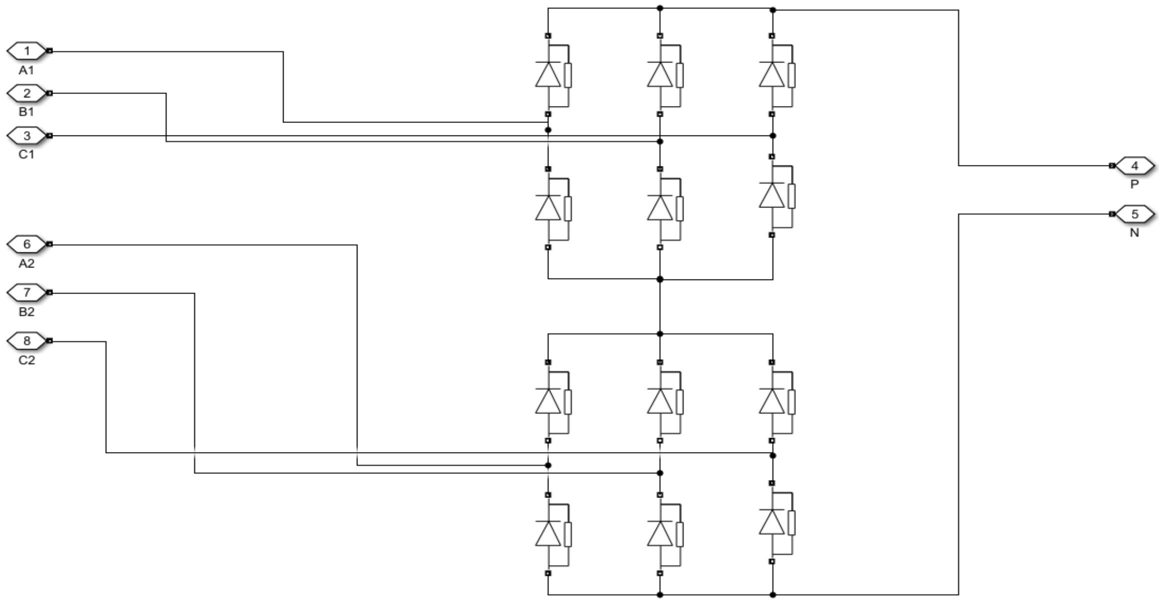

Figure-15: 100kW AC-DC Converter as implemented on MATLAB Simulink

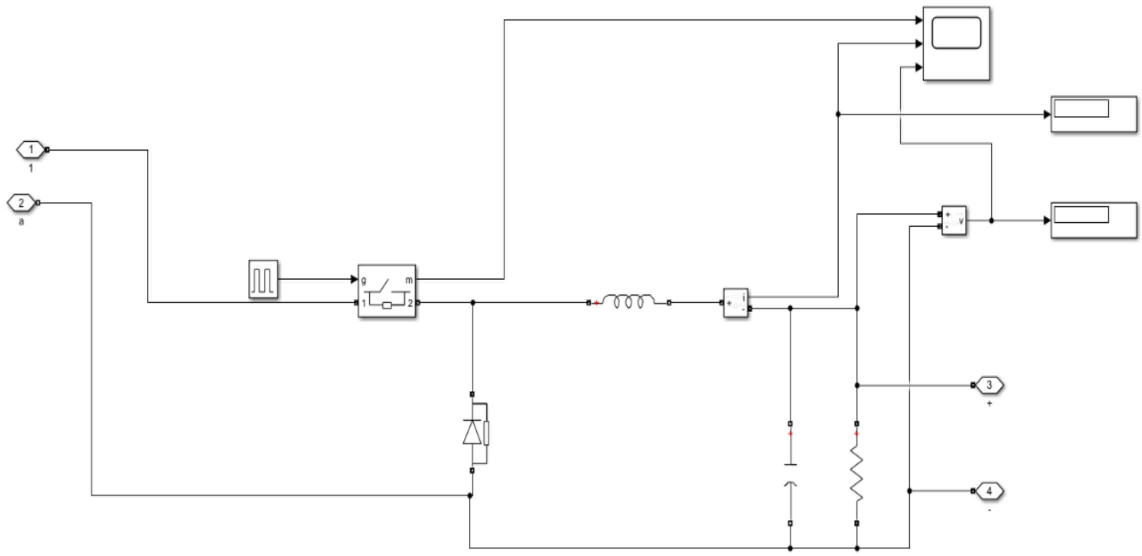

Figure-16: DC-DC Converter as implemented on MATLAB Simulink

DC-DC connectors shown in Figure-16 are designed in order to provide the output voltages required by each connector type: CHAdeMO requires 500Vdc while CCS connectors require 1000Vdc output voltage.

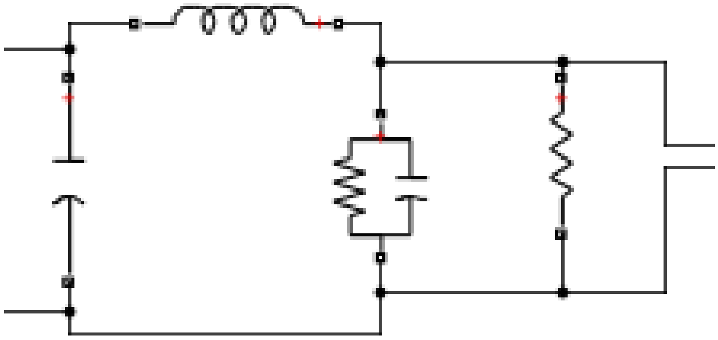

Figure-17: Filter as implemented on MATLAB Simulink

In order to remove any ripples in the output DC voltage, the filter in Figure-17 was implemented, consisting of capacitor and inductor to reduce any ripple and overshoot.

Charging Station Surge Protection

Surge protection in EV charging stations is paramount for safeguarding both the station's infrastructure and the connected electric vehicles. It shields against voltage spikes caused by lightning strikes, power grid fluctuations, or electrical faults [6], preventing damage to charging equipment and ensuring safe and reliable charging operations. Figure-18, shows a surge protection layout fo Surge protection and comprehensive safety systems are essential to safeguard against voltage spikes and other electrical anomalies, ensuring the longevity of the charging infrastructure and human safety, in addition to the safety standards in charging stations which are crucial to ensure the protection of users and equipment an EV charging station.

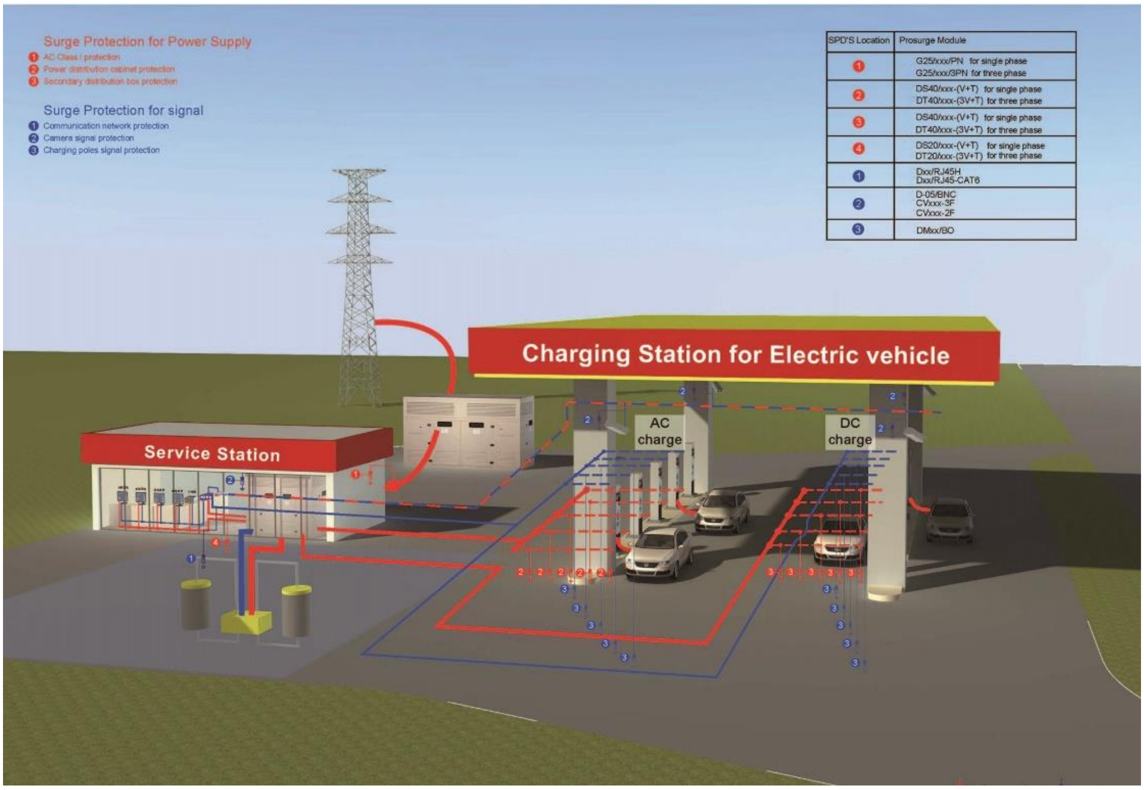

Figure-18: EV Charging Station Surge Protection

By implementing the appropriate safety measures and system, this will prevent electrical hazards, minimize risks of fire, and ensure reliable operation of the station. [7]

RESULTS, SIMULATION AND CALCULATION ANALYSIS

This section will discuss the results of the designed DC fast charger using MATLAB-Simulink. The charger includes two 1000V outputs compatible with Combined Charging System (CCS) connectors and one 500V output compatible with CHAdeMO. The simulation results demonstrate the charger's ability to efficiently manage power distribution and maintain voltage stability across different connectors. The designed DC fast charger shown in Figure-19, features two CCS

(Combined Charging System) connectors and one CHAdeMO connector. The CCS connectors are rated at 1000 VDC with a combined power of 300 kW, divided as 175 kW and 125 kW, respectively. The CHAdeMO connector is rated at 500 VDC with a power rating of 100 kW. The design includes:

- Three-phase transformer that steps down the high voltage from the source to a suitable level for the AC-DC conversion, thus ensures isolation and voltage regulation for the AC-DC converter.
- AC-DC converters which are three-phase full-bridge rectifiers [10], that efficiently convert AC voltage from the transformer to DC voltage. Key performance metrics include the total harmonic distortion (THD) of the input current and the power factor.
- DC-DC converters that maintain stable DC output voltage levels for the CCS and CHAdeMO connectors.
- Filters to reduce output voltage ripples to ensure smooth DC output [11].

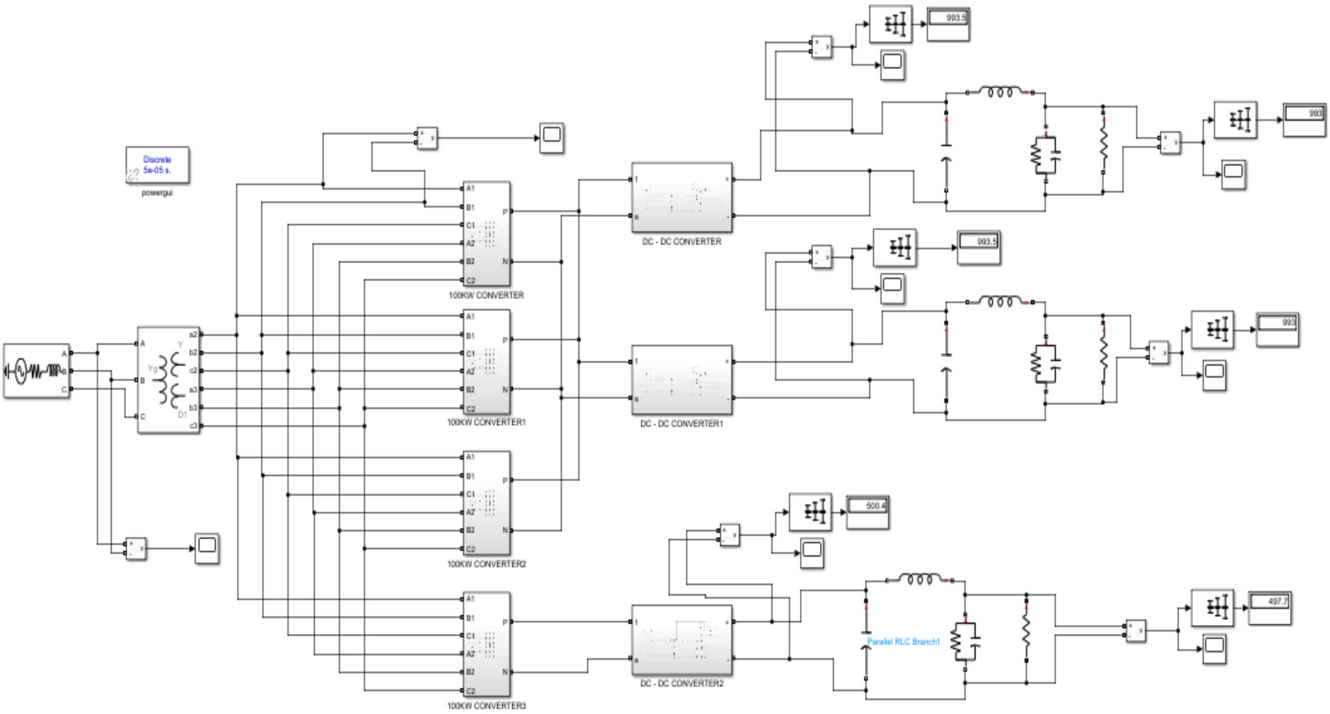

Figure-19: Results in MATLAB

Figure-20 shows the three-phase grid voltage before the step-down transformer, and Figure-21 shows it after the step-down transformer where the voltage was stepped-down to approximately 850V.

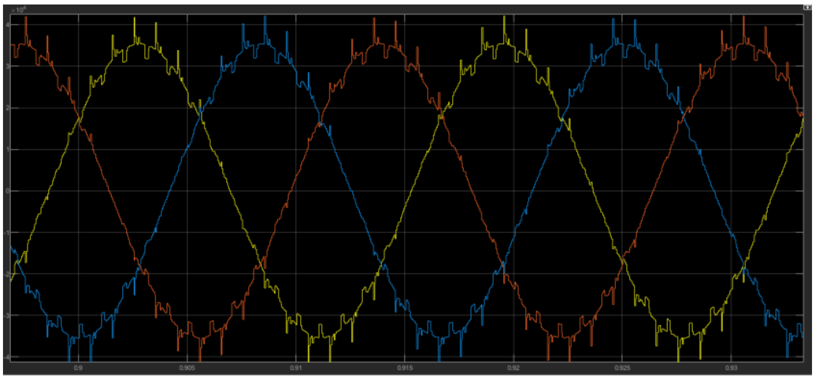
Figure-20: Three-Phase Grid Voltage

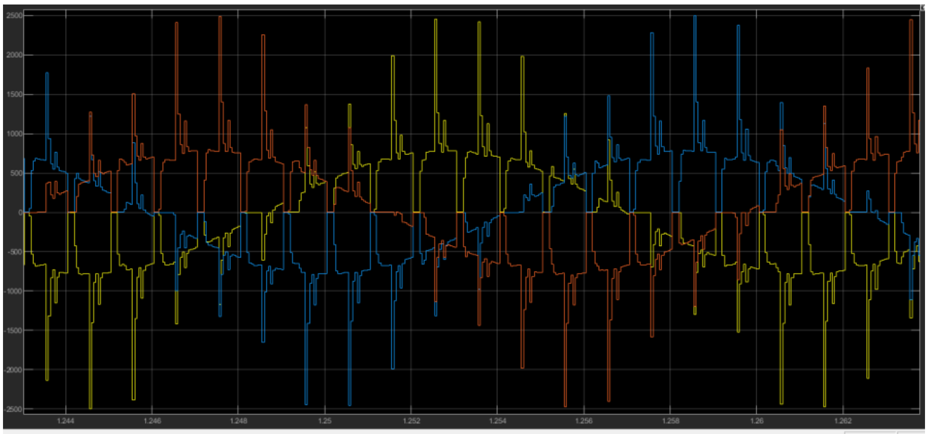

Figure-21: Three-Phase Grid Voltage after Step-Down Transformer

The following results show the ripple in the voltage curves, this ripple could be eliminated by using an EMI filter.

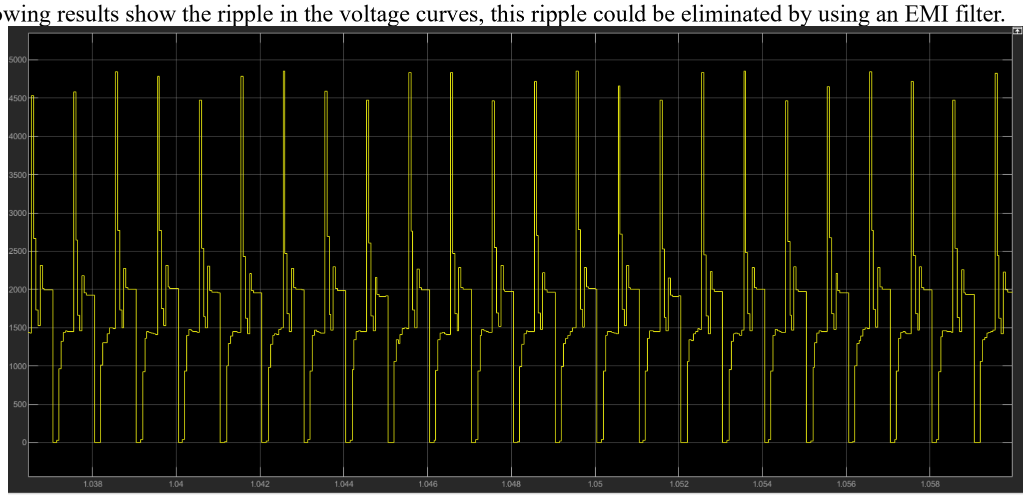

Figure-22: DC Voltage with Ripple

Figure-22, shows the DC voltage resulting from the AC-DC conversion, the figure shows ripples in the waveform, that are eliminated by the DC-DC converter and a filter in order to reach to the desired smooth output voltage.

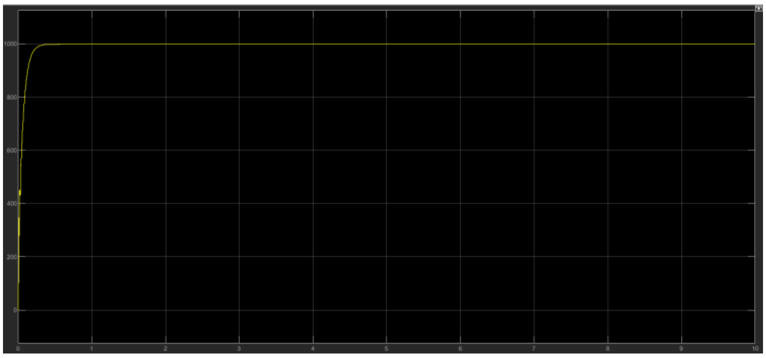

Figure-23: Output Voltage 1000Vdc for CCS Connector

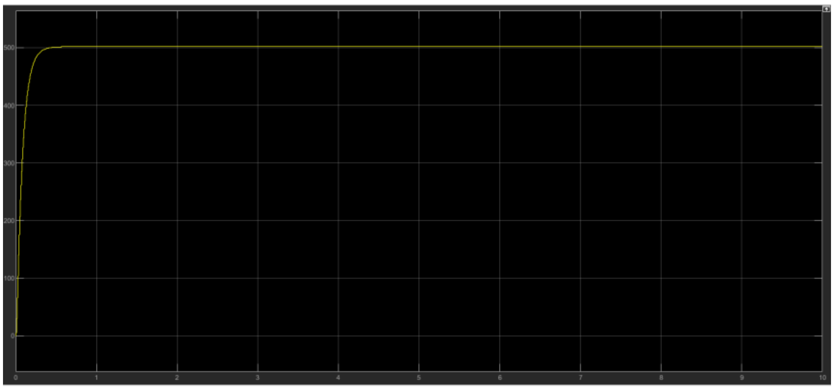

Figure-24: Output Voltage 500Vdc for CHAdeMO Connector

Figure-23 and Figure-24 show the output DC voltage after the DC-DC conversion that converted the voltage from an average of 2500V to 1000Vdc for CCS and 500V for CHAdeMO with pure DC waves. The filter designed in Figure-16 has effectively eliminated the ripples and spikes to result in the curves shown in figures-23 and 24. It can be noticed how the implemented filters effectively reduced the output voltage ripples. The ripple voltage is maintained well within the acceptable range for both CCS and CHAdeMO connectors, ensuring smooth and reliable charging.

a) Results Analysis:

- CCS Connectors:

1) 175 kW Output: achieved stable 1000 VDC with minor fluctuations (within acceptable limits), delivering 175 kW.
2) 125 kW Output: also achieved stable 1000 VDC with minor fluctuations, delivering 125 kW.

- ChAdeMo Connector: achieved stable 500 VDC output with minor fluctuations, delivering 100 kW.

b) Calculation: In order for the user to estimate the charging period required to charge his EV, this could be calculated by dividing the required charging amount by the power delivered from the charging connector. For example, for an Audi e-tron GT:

- Battery capacity= 93.4 kWh (usable capacity is around 85kWh)
- Maximum DC fast charging rate: up to 270 kWh

  Estimated charging time using a CCS 175 kW connector from 10-80% is:
  Required charge=70%
  85kWh*0.7=59.5kWh
  59.5/175= 0.34 hours which is around 20 minutes.

CONCLUSION

As a conclusion, this paper focuses on accelerating charging and enhancing safety in electric vehicle charging stations, ensuring a sustainable future in the transportation field. DC fast chargers reduce EV charging times making them more convenient and practical for everyday use, they provide higher power output enabling a faster charging process which is crucial for long distance drivers with limited charging times. This technology supports greater adoption of electric vehicles and improves the overall efficiency and effectiveness of EV charging stations. Moreover, there are international standards to ensure proper grounding, insulation, and surge protection, minimizing the risk of fire and electrical shocks in EV charging stations. Adhering to these protocols guarantees a safe and reliable charging experience for all users. The strategic deployment of DC fast chargers also supports grid stability by enabling more efficient energy management and integration with renewable energy sources, contributing to a more sustainable and resilient energy infrastructure. To sum it up, the adoption of electric vehicles (EVs) is expected to surge in the coming years, driven by advancements in technology, declining costs, and increased environmental awareness. Government policies and incentives, along with expanding charging infrastructure, will further accelerate this transition. As EVs become more accessible and efficient, they will play a major role in advancing global sustainability goals as they position themselves to dominate the automobile business.

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