DP2 Project Report

Jason Li
xl3303@nyu.edu
Department of Electrical and Computer Engineering

***Abstract*—The objective of the project is to construct an electric vehicle charging station that gives a stable output and prevent from overloading. A 380V 3-phase AC source, a three-winding transformer, a 12-pulse rectifier were used in the power system. LC filter and PID controlled pulse width modulation were used to control the output voltage. The results of the simulations follow the expectations, and the charging station functions well in a large power system.**

***Index Terms*— Electric Vehicle charging, LC Filter, Energy Distribution, ACDC/DCDC converters, PWM.**

I. Introduction

Electric vehicles (EVs) are becoming increasingly popular worldwide due to their low carbon emissions, high energy efficiency, and potential to reduce dependence on fossil fuels. In California alone, it is estimated that there will be at least 1.5 million EVs [1]. However, a significant obstacle to the widespread adoption of EVs is the lack of public charging infrastructure. This is where the importance of EV charging stations becomes evident. The Department of Public Utilities has approved the installation of up to 1500 charging stations in Southern California and 3500 chargers in San Diego [1]. Given this high demand, it is crucial to design efficient charging stations to minimize energy loss and facilitate faster charging.

Efforts to enhance power transmission efficiency in charging stations have led to notable advancements. Li et al. developed high-frequency PCB winding transformers with integrated inductors, aiming to reduce converter size and increase efficiency [2]. Cittanti et al. utilized Three-Phase LCL Filters to address current total harmonic distortion (THD) concerns [3].

The project's objective is to construct an EV charging station that delivers a stable power output with minimal harmonics and grid impact. The charging station comprises two chargers, each equipped with two ports. Each charger can provide a maximum power output of 120 kW for a single car and 160 kW when simultaneously charging two cars. It supports two-phase charging: constant current phase and constant voltage phase, which ensure the safety of the charging process. The ripple current and voltage are maintained at approximately 1A and 1V, respectively. It also needs to operate properly in a large power system. However, it is important to note that the design lacks support for Vehicle to Grid functionality, meaning that the power transfer is unidirectional. Additionally, the maximum power capacity of the charger falls short when compared to commercial DC chargers.

In the project, a 12-pulse rectifier is employed to convert the AC input into a DC output. To filter out low-frequency signals, an LC filter is utilized. In order to enhance the performance of the DC-DC conversion, two buck converters are implemented in parallel. Two pulse width modulation blocks are utilized to control the switching frequency of the MOSFETs. These measures contribute to the production of a stable power output from the chargers.

A stable power output is of utmost importance for EV chargers as it ensures proper and efficient functionality. It plays a crucial role in preventing the charger and EV battery from damage, promoting optimal performance, and reducing the risk of electric shock.

II. Analysis of Applicable Standards

The limit on the power quality of the converters is prescribed by IEEE Standard 519[4], in which it says that the maximum amount of harmonic current or voltage that a single harmonic can contribute is 3% and 1% respectively. According to IEEE Standard for a DC quick charger says that the ripple current under a operation frequency with 5k HZ or less should be within 3A [5].

III. Theoretical Considerations

Several factors must be carefully considered in the design process, including power capacity, charging time, and construction costs.

Determining the power capacity requires assessing the expected demand for the charging station and evaluating the electrical infrastructure in the vicinity. This ensures that the station can meet the power requirements of EVs without causing electrical disruptions or overloading the system.

The charging time, which is influenced by the output power, should be designed to meet the needs of an EV charger. To achieve this, reference standards such as EVDC-150NA from Evesco can be used to guide the power requirement specifications and optimize the charging time.

Cost is also a significant factor to consider. High-capacitance capacitors can be expensive, so designing the circuit with efficiency in mind can help minimize the required capacitance for voltage stabilization. This approach allows for cost savings while maintaining stable voltage levels.

By carefully considering power capacity, charging time, and construction costs, the design can strike a balance between meeting the demand for EV charging, optimizing charging time, and ensuring cost-effectiveness in the construction process.

IV. DESIGN

The construction of an EV charging station can be categorized into three main parts: the AC side, the DC side, and the PWM block.

On the AC side, a 480V-50Hz three-phase voltage source is utilized. To transform the voltage, a three-winding transformer with a turn ratio of 480/380 is employed. The YD11 wiring configuration is chosen due to its compact design, high efficiency, and low noise levels. Furthermore, this configuration meets the necessary safety standards required for charging EVs.

For the DC side, a 12-pulse rectifier is implemented to convert the AC input to DC. This rectifier comprises two 6-pulse rectifiers connected in parallel. Each rectifier is connected to a separate transformer winding, ensuring a phase shift of 30 degrees between them. This configuration significantly reduces the presence of harmonics in the output, contributing to a smoother DC signal.

In the PWM block, pulse width modulation techniques are applied to control the switching frequency of the MOSFETs. This allows for precise control of the power output and facilitates efficient energy conversion within the charging station.

By dividing the construction into these three parts, the design of the EV charging station can be organized, ensuring proper functionality, efficiency, and adherence to safety standards.

The design of the AC side is shown below in figure 1.

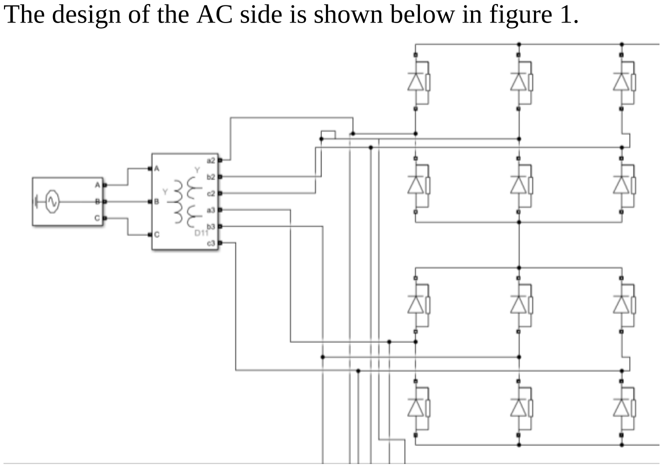

Figure 1: AC side design

As for DC side, an LC filter is used to filter out the noises and reduce the ripple voltage. The inductance is 0.5H and the capacitance is 1500 μF. The cut-off frequency is 5.81Hz. The calculation is shown below in formula (1).

$$f_c = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.5*1500*10^{-6}}} = 5.8115Hz \quad (1)$$

Two buck converters are connected in parallel so that the charger can adjust voltage according to the power requirement. A variable resistor that decreases the resistance as time goes on. This can act as a soft starter for the circuit so that there will not be in-rush current at the beginning. Figure 2 shows the configuration of the DC side.

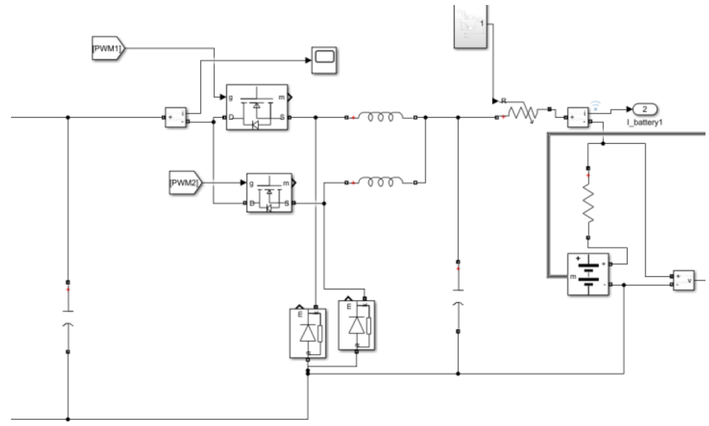

Figure 2: DC side design

The measurement and display ports of the system include the State of Charge (SoC) and voltage of the battery, as well as the current and voltage of the load. The battery model consists of a 0.3Ω resistor in series with a battery that has a nominal voltage of 600V and a capacity of 150Ah.

Control over the output voltage is achieved through the manipulation of the switching frequency. This is accomplished using Pulse Width Modulation (PWM) and a PID controller. By adjusting the pulse width based on the PID error value, the PWM can deliver more or less power to the system in order to correct any deviations from the desired setpoint. The controller design is depicted in Figure 3.

By continuously monitoring the SoC and voltage of the battery, as well as the current and voltage of the load, the system can effectively regulate the output voltage to maintain stability and meet the desired performance requirements.

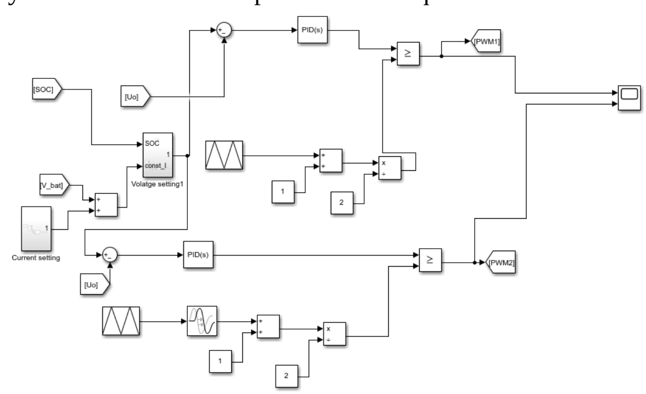

Figure 3: PID-PWM design

Within the system, there are two blocks known as the current setting and voltage setting, both serving as soft-starters. These blocks incorporate ramps and switches to gradually increase the voltage. If the desired current is 100A, the expected voltage value will be set at 30V higher than the battery voltage.

The charging period consists of two phases: the constant current phase and the constant voltage phase. During the constant current phase, which occurs when the State of Charge (SoC) is below 50%, the battery is charged with a constant current.

The charging station is equipped with two charging ports, each capable of simultaneously charging two cars, as illustrated in Figure 4. This configuration allows for efficient charging of multiple electric vehicles at the same time, optimizing the utilization of the charging station's capacity.

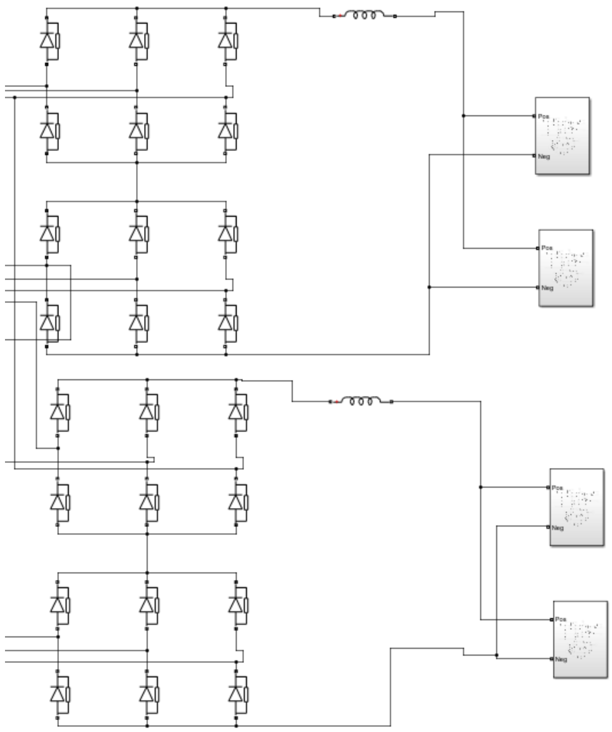

Figure 4: Charging ports

V. Experimental Result

The case studies are as follows:

1. One EV per charger with a maximum power output of 120kW.
2. Two EVs for charger 1 and one for charger 2. Charger 1 has an output current of 110A, charger 2 has an output current of 200A.
3. Two EVs for both chargers, each with an output current of 110A.

These case studies aim to assess the efficiency and performance of EV charging systems in different scenarios, providing valuable insights into the strengths and weaknesses of various charging configurations.

In Case 1, both chargers operate with an output current of 200A. The charging process demonstrates a stable behavior, with the current initially increasing to 210A and gradually decreasing to the desired 200A. The total harmonic distortion relative to the DC component is measured to be 0.08% and 0.06%. The charging current pattern is visually presented in Figure 5, allowing for a comprehensive understanding of the charging process.

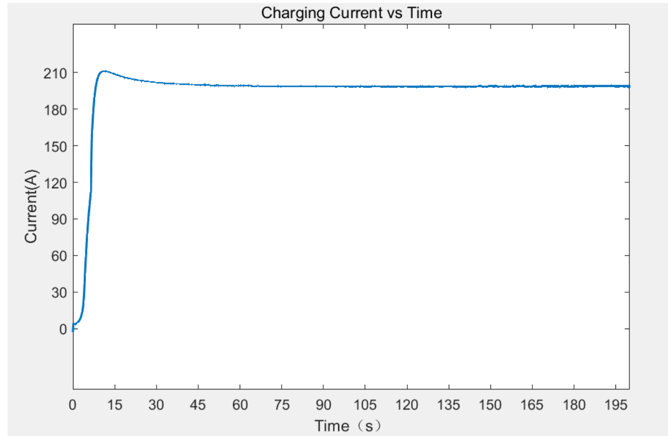

Figure 5: Charging vs Time (Case 1)

The state of charge increase slowly as time goes on, as shown in figure 6.

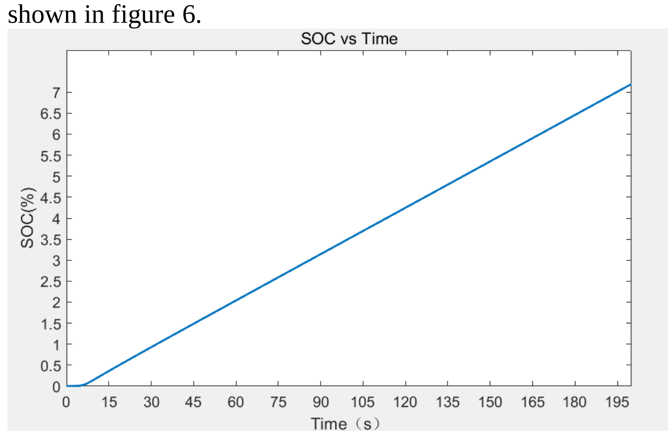

Figure 6: SOC vs Time (Case 1)

The voltage of the battery increases from 510V to 610V slowly and smoothly, which indicates that the charging process is safe and sound.

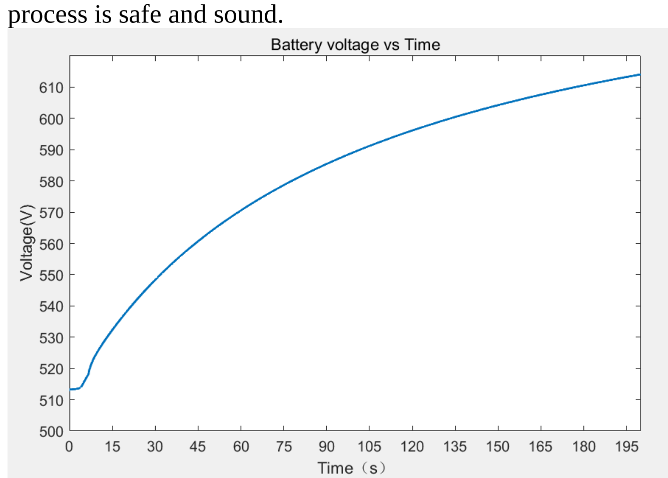

Figure 7: Battery voltage vs time (Case1)

In Case 2, the State of Charge (SOC) is initially set at 47%. As the SOC increases and reaches 50%, the charging mode transitions from constant current to constant voltage. Consequently, the charging current decreases from 110A to 80A, as depicted in Figure 8. Similarly, the second port, which has an output current of 200A, follows a similar charging pattern as illustrated in Figure 5. The THD for both chargers are 0.12% and 0.08% respectively.

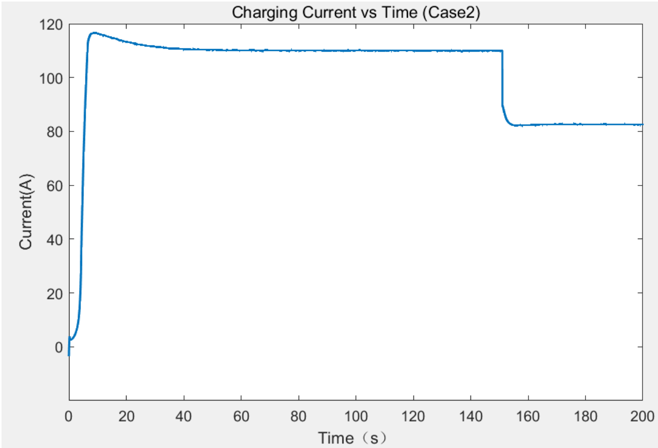

Figure 8: Charging vs Time (Case 2)

As the charger gets to constant voltage mode, the voltage drops and remains around 650V, which is below the fully-charged voltage. The plot is shown below in figure 9.

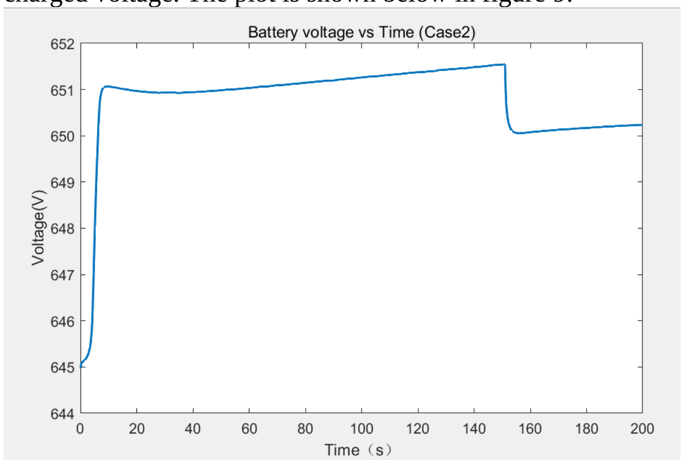

Figure 9: Battery voltage vs Time (Case 2)

In Case 3, the output current for all four chargers remains stable at 110A. The patterns observed for the charging current, voltage, and State of Charge (SOC) are similar to those presented previously. The THD for all charging ports is measured to be 0.12%.

The SOC is set to 99.8% and the charging process terminates when it reaches 100%. The SoC remains the same after the battery gets fully charged, which is shown in figure 10.

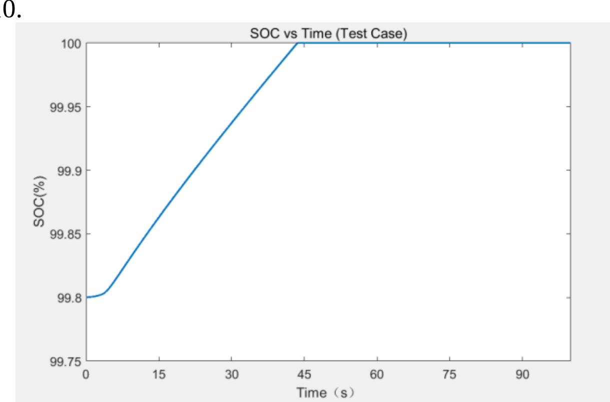

Figure 10: SoC vs Time (Test Case)

To assess the performance of the charging station in a larger system, it is integrated into an IEEE 13 Node system. Prior to the inclusion of the charging station, each node in the system operates within the acceptable voltage per unit range of -1.05 to 1.05.

After the charging station is added to the system, the voltage levels at all other nodes continue to operate within the regular range of 1.05 V per unit. Additionally, the voltage per unit at the charging station system is measured to be 1.01 pu, 1.02 pu, and 1.01 pu for the three cases studied. This indicates that the charging station system functions properly within a larger system without causing significant disruptions or deviations in the voltage levels.

Overall, the case study demonstrates that the charging station system can effectively operate within a larger power distribution system, maintaining stability and adhering to the voltage requirements.

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VI. Conclusion

The project has successfully fulfilled the objectives of designing and implementing an efficient and reliable EV charging station. This is demonstrated through several key aspects outlined in this report.

The stability of the output current and voltage for all charging ports stratify the requirement for power output. The simulations and measurements conducted in different case studies consistently show stable output currents and voltages, with low ripple and THD values.

The control over the power flow, achieved through the PWM block, confirms the successful implementation of power flow control. The ability to set the output current prior to the charging process ensures precise control and optimization. The two-phase charging approach, with constant current and constant voltage phases, ensures safe and efficient charging while preventing the battery voltage from exceeding its nominal value.

Furthermore, the integration of the charging station into an IEEE 13 Node system demonstrates its compatibility and normal operation within a larger power distribution system. The voltage per unit of the charging station and other nodes remains within the acceptable range, indicating that the charging station does not cause disruptions or deviations in the overall system.

Thereby, the construction of the EV charging station is successful.

VII. Recommendations

Based on the results of this project, several recommendations can be made to improve the efficiency and performance of the EV charging station:

1. Increase the number of charging ports: With the increasing demand for EV charging stations, adding more charging ports to the existing station can help make money and enhance production.
2. Explore renewable energy sources: Renewable energy sources like solar and wind can be used to power the EV charging station. This can help reduce the operating cost of the station and make it more sustainable.
3. Implement smart charging: Implementing smart charging can help optimize the charging process, reduce the peak

demand on the grid, and save money on energy costs. A VIP feature can be developed so that those who pay more can charge faster during high peak.

In continuation, more work can be done to improve the EV charging station design. The charging process can be optimized further to reduce charging time while ensuring battery safety. More efficient power electronics can be used to improve the power conversion efficiency of the station.

VIII. References

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