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Interoperable Multiport DC Charging System with Optimal Charging Management Strategy for Electric Vehicle Fleet Charging Hub

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Executive Summary

This paper presents an approach to designing and managing commercial EV charging hubs through an interoperable multiport low-power Direct Current (DC) charging system integrated with hierarchical charging management. The proposed system architecture leverages modular design principles to enable flexible and scalable deployment of multiport charging infrastructure, catering to varying demand levels without requiring extensive initial investment. Key elements include modular power units that can be dynamically configured and expanded, providing a cost-effective and adaptable solution for growing EV markets. It is investigated from the 45kW laboratory testing, the modular 45kW DC charging station improve the station efficiency by 2% at full load compared to the dedicated 45kW charger module. A hierarchical charging management system is introduced to optimize the allocation of power resources. This system incorporates real-time load balancing, dynamic power distribution, and prioritization algorithms to manage multiple charging stations efficiently. By distributing power based on real-time demand and predefined priorities, the system enhances the overall performance, reliability, and user experience of the charging hub. the overall charging cost can be reduced by 31% by incorporating optimized charging scheduling strategy in modular DC charging station. The prototype is implemented to validate the proposed charging system in the laboratory environment.

Keywords: Electric Vehicles, AC & DC Charging Technology, Smart Charging, V2G

1 Introduction

The rapid advancement of electric vehicle (EV) technology has ushered in a new era of transportation characterized by sustainability and innovation. As the demand for EVs continues to rise globally, the development of robust charging infrastructure and vehicle-to-X (V2X) systems is paramount to support widespread adoption and maximize the benefits of electrified mobility. According to [1], 6.8 million public and 29.4 million private charging points installation is planned by 2030 in the EU region for both urban and rural areas. It is also estimated that there will be 5 EVs are allocated for each charging ports in rural areas and around 7 EVs allocated for the same in rural areas. There is a need of a Fleet-based applications such as public transportation, logistics, and ridesharing require scalable, efficient, and intelligent charging systems to ensure operational reliability and minimal downtime. In this context, the development of multiport DC charging systems is gaining traction due to their ability to provide high-power, simultaneous charging across multiple EVs with improved energy efficiency and reduced conversion losses compared to conventional AC systems [2], [3]. While modular multiport chargers offer scalability and fault tolerance [4], their practical deployment is often hindered by several challenges. First, modular charging systems necessitate high initial investment costs due to the required upgrades in power infrastructure, such as new transmission and distribution lines [5], [6]. Despite the cost of such system equipment's being approximately ten times higher than that of conventional chargers, the faster return on investment is achievable as modular systems can serve more vehicles daily. Additionally, the impact of modular systems on voltage stability in the distribution network is a critical concern. Voltage fluctuations and flicker caused by high power demand can disrupt the network [7], although these issues can be mitigated with smart charging algorithms and on-site distributed energy resources [8]. Another challenge is the wide variation in charging capacities among different EV models. This variation complicates the sizing of charging stations. If a station is designed for the maximum allowable charging power, it often operates at a lower efficiency, as it rarely runs at full capacity. Furthermore, unmanaged or poorly coordinated charging of large EV fleets can lead to grid stress, increased operational costs [9].

To address these challenges, this paper proposed an interoperable modular multiport DC charging system integrated with an optimal charging management strategy tailored for EV fleet charging hubs. The proposed architecture supports bidirectional power flow, scalable hardware modules, and intelligent scheduling algorithms that dynamically allocate power based on vehicle priority, state-of-charge (SoC), and departure time. The interoperability is ensured through compliance with established communication standards and adaptive control protocols. Experimental validation on a 45kW prototype demonstrates high system efficiency (>95%), controlled THD, and effective power distribution across ports. The proposed solution addresses key technical and operational challenges in EV fleet electrification and offers a path toward reliable, grid-supportive, and cost-effective fleet charging infrastructures.

2 Proposed Multi-port Charging Station

The proposed low power modular charging system is shown in Figure. The detailed system description is discussed below. The proposed modular charging solution comprises 2 containers which supply 2 charging ports. Each charger container contains 3X15 kW AC/DC converter and 1X50 kW DC/DC converter. The system is hybrid because the charging station is powered from both AC grid and other energy sources (such as BESS). BESS is essential for high power EV charging station design due to its ability to manage demand peaks, ensure grid stability, improve efficiency, reduce costs, enhance reliability, support renewable integration, and enable fast charging. By integrating BESS, EV charging stations can operate more effectively, sustainably, and economically, meeting the growing demand for electric vehicle charging infrastructure. The grid supply is not only utilized as an AC supply for the charging container, but also used to charge the battery during off-peak hour (electricity price is low) through AC/DC converter. The charging station consists of two groups of power converters. The AC/DC converter group has a 3x15 kW modular structure to serve the charging power to the L3e (passenger cars/vans) and emulate a scaled charging system. There are 3 charging ports for each charging container which means that 3 EVs can be charged simultaneously with 15 kW charging rate. There are two charging containers with similar containers connected to a DC relay. Thus, the charger can charge a single port up to 90 kW if all charging ports are available. The charging station capacity is scalable which depends on the availability of the charging port. For example, 4 charging ports can charge 4 vehicles with 22.5 kW charging rate. Similarly, 2 charging ports can charge 2 vehicles simultaneously with 45 kW. This charging power sharing is possible through parallel connection of the PE converters via relay switch. The charging system configures the contactors (Rx) of the AC/DC modules for power sharing to support high power charging. Here, x = 1, 2, 3… indicates the number of modules required to activate. The power sharing strategy is needed to ensure the module activation during higher power charging.

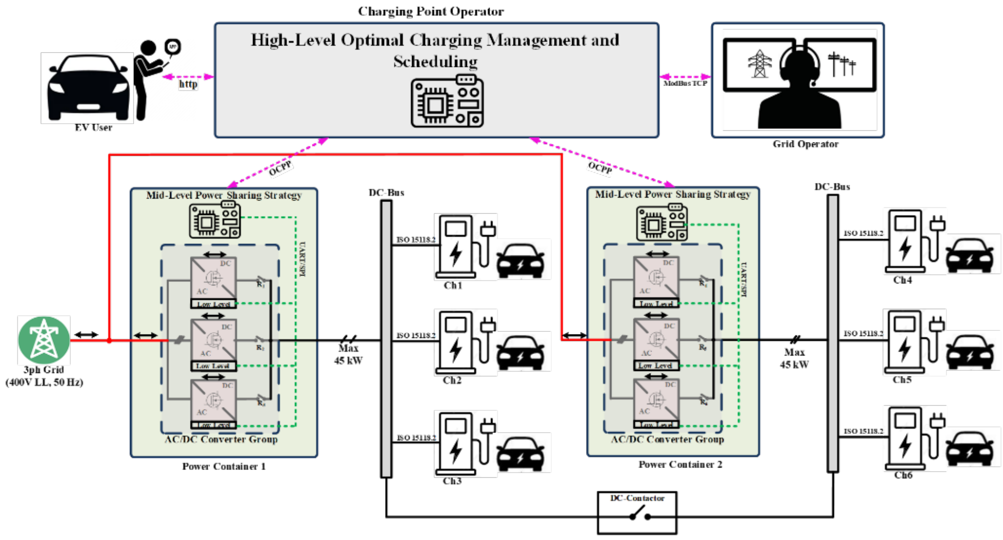


Figure 1: Proposed Charging System Layout.

The mid-level module power sharing controller allocates the reference power (P_{ref}) signal which is coming from high-level optimum charging scheduler. The core function of the charging scheduler is to generate the required power reference to optimize the charging cost. To perform this optimization, the high-level charging scheduler required the external signal such as forecasted electricity price (€/kWh), EV user information (arrival time, departure time, initial SoC, Slow/Fast Charging), EV battery information (battery capacity, SoC status), total charging load demand etc. The required charging power profile is generated via convex optimization algorithm which transmits to the mid-level power sharing algorithm to allocate the power among the modules.

3 Optimal Charging Management and Power Flow Control Strategy

Figure 2 is shown the multilevel charging station management and control strategy which is considered for proposed hybrid charging station. The levels are High Level, Mid-Level and Low Level. The high level aims to introduce intelligence in the whole microgrid which above sections so that an optimal operation for charging station can be achieved.

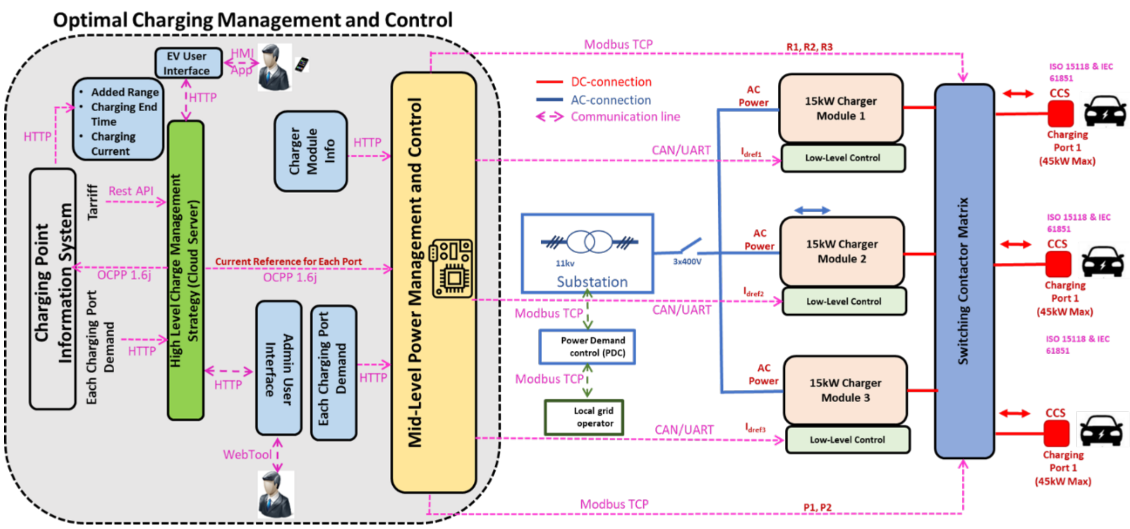


Figure 2: Block diagram of optimal charging management and power flow control strategy including communication and control signals.

The high-level management strategy described in [10] uses GA algorithms to optimize the cost that are used in this level to gather information and take actions, mainly focused on managing the power flow between the

ESS, the utility grid and the charging load. This level has the slowest regulation speed, and the control is executed in time steps ranging from seconds to hours. The primary function of high-level management is to generate the required current reference for each charging load request via optimizing the charging cost for the user. The mid-level operates on top of the low level. It deals with power flow and quality control and adjusts for voltage, current or frequency deviations caused by the primary level for every power electronic converter of the master station. Compared with the high level, it has a faster response (100ms - 1s) to variations. The low level is the lowest level in the control structure. It performs the control of local power, voltage and current loops and ensures the normal operation of each power converter. It has the fastest response (1 - 10ms) to any variation of the demand or the power sources.

3.1 High-level Charging Management Strategy (HL-CMS)

In this work, convex optimization strategy is utilized to generate the charging current profile from high-level charging management block by optimizing the charging cost. The optimization algorithm aims to minimize the charging cost for the EV operator, while satisfying the requirements and constraints of the EV and grid operators. The HL-CMS is adopted using convex optimization in this research work which applies to charging stations. The strategy initiates upon arrival of the EV in the charging station. When an EV arrives at a charging station, the driver informs the EVSE of his or her needs. The charge request is received by the HL-CMS, which then performs the real-time scheduling and optimization algorithm. The scheduling of the EV charging process is deemed difficult due to the wide range of limitations imposed by many parties. This makes it challenging to develop charging schedules that are viable, efficient, and acceptable to all stakeholders, especially when numerous EVs must be charged at the same time. The detailed explanation of mathematical formulation for optimization problem is out of scope for this paper. Mathematically, the optimization problem is formulated from Eq. (1) – Eq. (5) as follows:

$$Minimize\left(\sum_{i\in N}\left(\beta_0 y_i + \frac{\beta_1}{2} y_i^2\right)\right) - \left(\beta_0 P_i^b + \frac{\beta_1}{2}\left(P_i^b\right)^2\right) \quad (1)$$

$$Subject\ to$$

$$y_i = P_i^b + \sum_{m\in M} p_{mi} S_{mi}, \forall i \in N \quad (2)$$

$$0 \leq SoC_m^{ini} + \sum_{i\in N} dp_{mi} S_{mi} \leq SoC_m^{max}, \forall i \in N, \forall m \in M \quad (3)$$

$$SoC_m^{ini} + \sum_{i\in N} ip_{mi} S_{mi} \geq \alpha_m SoC_m^{max}, \forall i \in N, \forall m \in M \quad (4)$$

$$0 \leq p_{mi} \leq P_{max}^{ch}, \forall i \in N, \forall m \in M \quad (5)$$

In the optimization problem which is adapted from [11], the objective function Eq. (1) is convex, and all the constraint functions are linear. Therefore, the optimization problem (5) is a convex optimization problem, which can be solved efficiently with the interior point methods [12]. Here, the number of intervals is denoted as “N” which is divided into 24 h and each interval duration is i = 1h. Moreover, “M” represents the total number of EV which is booked for charging. Each EV iterated as “m” during calculation. The total power demand of the site including EV charging load is represented as “y” which represents the base load (P^b_i). The charging-interval matrix (S_{mi}) is generated from EV user input to track the expected charging duration. The initial and maximum SoC of each EV is denoted as SoC^{ini}_m and SoC^{max}_m which considered and kWh unit. Similarly, the charging rate is denoted as p_{mi} which can go up to maximum charging rate (P^{ch}_{max}) during optimized charging profile generation.

3.2 Mid-level Power Management Strategy

The mid-level management strategy coordinates all the power electronic converters during the charging process as shown in Figure 3. The strategy allows the activation of the charger module depending on the load demand. The main functionalities of mid-level power management strategy are power sharing among the power electronic converters and charging power flow control. This management system comprises 3 significant functional blocks such as current reference signal generation, module power sharing, and AC or DC power flow control.

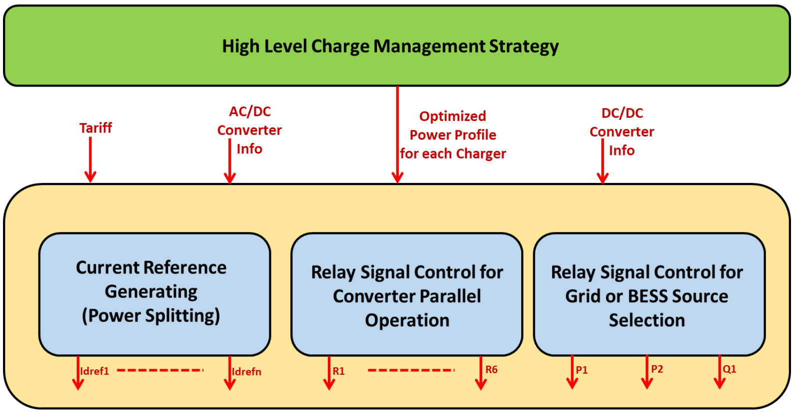


Figure 3: Mid-level charging management and control interlinked with HL-CMS.

The main aim of power splitter block is to generate the current reference signal which should communicate to the low-level control of the individual power converter. The total charging current (I_{dtot}^*) which generated by the high-level management block is utilized as the input of the block. Based on the total requested current (I_{dtot}*), and the current rating per module, the system calculates how many modules (N_{active}) need to be active by using Eq. (6). Then, based on its module logical position, the module identifies if it needs to be active. If the system is to stay active, it calculates its reference d-axis

$$N_{active} = \frac{I_{d\,tot}^*}{I_d^{rated}} \quad (6)$$

$$I_{d1\ldots n}^* = \frac{I_{d\,tot}^*}{N_{active}} \quad (7)$$

current by dividing the I_{dtot}* by the number of active modules as given in Eq. (7). The relay control block for parallel operation activates more power converter module to fulfil the power demand by sending current reference to low level controller of activated PE converter. However, there is a limitation in switching sequence for module activation. Each charging port can fulfill the charging demand up to 15kW max by rearranging the switching matrix if both ports are connected to EV. Thus, one charging station is also able to charge 45kW if the other charging port is disconnected from EV. For example, the EV connects in port 1 with 15kW charging demand (slow charging). During this time the charging station management will connect the charger module 1 by closing the contactor switch R1. There are 3 relays will be triggered in case 45kW charging demand. Likewise, the mid-level controller allows 90kW charging by switching all relays on (including DC relay). However, 90kW charging service is possible if all charging ports are disconnected from EV. Each of the converters has its own low-level controller, forced air-cooling fan, CAN communication port, and necessary voltage-current protection devices. There is a Raspberry Pi-based MCU module where the mid-level charging management is deployed to control the modular power-sharing strategy. The necessary current setpoints are estimated and transmitted to the CAN bus to ensure power sharing.

4 Results and Discussions

In this research, the considered timing of EV charging and discharging during a day (24 h) starting from 12:00 AM in midnight. The day is evenly divided into 24 intervals. Each interval has a length of 1 h. The optimized charging profile is the output of the high-level charging management block. The EV user inputs (such as arrival time, departure time, initial SoC, battery voltage, battery nominal capacity) are the significant input. The HL-CMS block generate the optimized power profile based on EV user input. In this section, one charging container is considered to analyze the results. There are 8 EVs are booked to charge with container 1. The EV user input for EV charger 1 is listed below Table 1. The total load is consisting with the base load, which represents the load of all electricity consumptions in interval except EV charging, and the charging load, which represents the load of EV charging. The optimizations of EV charging based on only temporal variation but not spatial variation of the price. The electricity price is modelled as a linear function of the instant load [5.8] which is shown in Figure 4. The charging station load profile with optimization and without optimization is shown in Figure 5. The "base station load without EV charging" refers to the power consumption or electrical load of a charging station when no electric vehicles (EVs) are being charged.

Table 1: Required EV user input to utilize the optimized charging or V2G profile

	Arrival Time	Departure Time	Initial Energy (kWh)	Nominal Voltage (V)	Nominal Capacity (kWh)	V2G Service
EV1	2 am	2 pm	10.36	400	37	No
EV2	2 pm	2 am	4.67	400	37	No
EV3	11 am	11 pm	8.94	400	37	No
EV4	1 pm	12 am	8.10	400	37	No
EV5	6 pm	12 am	12.34	400	37	No
EV6	12 pm	12 am	2.57	400	37	No
EV7	8 am	8 pm	7.65	400	37	Yes
EV8	1 pm	12 am	1.07	400	37	Yes

The graph compares station load under three scenarios over 24 hours: base load (blue), optimal EV charging (red), and naive EV charging (yellow). The base station load peaks around 97kW at 19 h–20 h and drops to a minimum of 17kW at the beginning of the day, giving a load range of 80kW. With optimal EV charging, the load increases more smoothly, peaking at 104kW near 23 h and reduced to 20kW at 0 h, resulting in an 84kW range. The increase is controlled, reducing stress on the grid. In contrast, naive EV charging shows peaks, especially between hours 6 h–8 h and 18 h–20 h, with a maximum of 102kW and a minimum of 18kW.

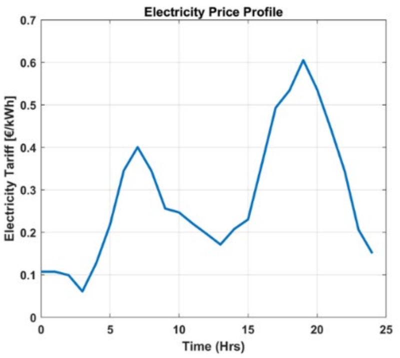


Figure 4: The electricity price profile whose variation followed the load profile pattern

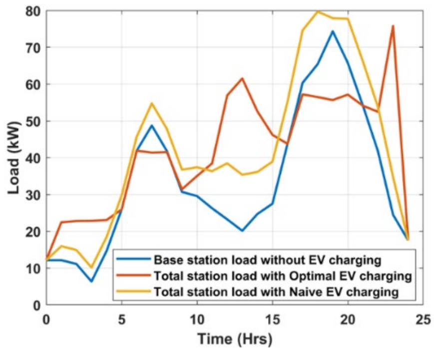


Figure 5: The impact of optimized CMS on overall station load profile

These sharp increments indicate simultaneous charging, which could not be beneficial for the infrastructure. While both EV charging methods raise the total load compared to the base case, optimal scheduling better distributes the load across the day by minimizing peaks. This makes it more efficient and grid-friendly than naive charging, which introduces volatile demand patterns. The top graph in Figure 6 shows the electricity tariff over 24 hours reach to the peak around 19 h at €0.60/kWh and dropped to a low near 3 h at €0.07/kWh. The bottom graph in Figure 6 compares the optimized charging profile with equally distributed charging profile which maintains a consistent load (~30–45 kW) throughout the day. In contrast, the optimized profile aligns charging with lower tariffs, concentrating loads during off-peak hours (e.g., 1 h – 3 h and 23 h – 24 h) and minimizing use during expensive periods (e.g., 18 h – 21 h). Notably, the optimal strategy even features negative loads during high-tariff hours, suggesting discharging or load shifting. This approach significantly reduces electricity costs by exploiting tariff variations.

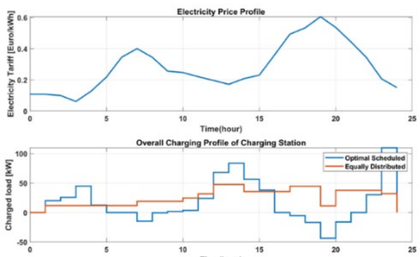


Figure 6: The scheduled optimized and non-optimized charging load profile for overall charging station with electricity price.

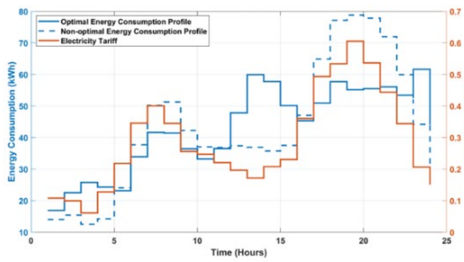
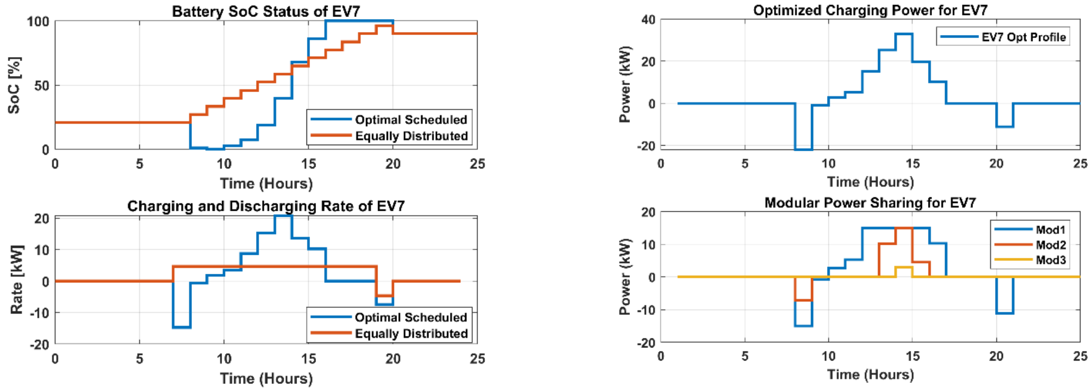


Figure 7: Energy consumption profile with optimal and non-optimal scheduling comparing with electricity price.

Figure 7 compares optimized and non-optimized energy consumptions against electricity tariffs over 24 hours. The electricity tariff (orange) peaks at € 0.65/kWh around hour 19 and drops to € 0.2/kWh in early morning and late-night hours. The optimal energy profile (solid blue) shifts consumption to lower-tariff periods, especially before 7 h and after 21 h. In contrast, the non-optimized profile (dashed blue) shows high usage during peak tariff times, especially between 17 h – 21 h, reaching nearly 75kWh. This optimization minimizes energy costs by avoiding high-tariff hours and concentrating use when electricity is cheaper.



(a) (b)

Figure 8: (a) Charging rate and SoC variation for optimized and non-optimized charging schedule (b) Modular power sharing performance during charging and V2G service with optimal scheduling.

The optimal charging management performance for EV7 is illustrates in Figure 8. The optimal scheduling strategy charges EV7 from 0% to 100% state of charge (SoC) between 8 h and 17 h, with a peak charging rate of approximately 20 kW around 14 h and discharging events reaching nearly -15kW at 7 h and 20 h which is shown in Figure 8 (a). In comparison, the equally distributed strategy increases the SoC gradually from 20% to approximately 90% over the same period, employing a constant charging rate of approximately 5 kW. The optimal schedule demonstrates a more dynamic and efficient utilization of power, enabling faster full charging by adjusting charging and discharging rates in response to temporal and system conditions. The optimized charging power profile for EV7 exhibits peak charging at approximately 14 h with a maximum power of 30 kW and discharging at around 8 h and 21 h, reaching nearly -20 kW. The corresponding modular power sharing shows that Mod1 contributes the highest share at 15kW, followed by Mod2 at 10kW, and Mod3 at 3kW. This coordinated modular allocation effectively supports the optimal profile by distributing the charging and discharging tasks among the three modules over time.

5 Experimental Validation of Proposed Charging Station

In this section, the experimental validation of the 45kW modular and scalable DC charging station is discussed. The aim of this section is the performance assessment of the modular DC charging station hardware setup including charging current sharing, power quality, bidirectional power flow, etc.

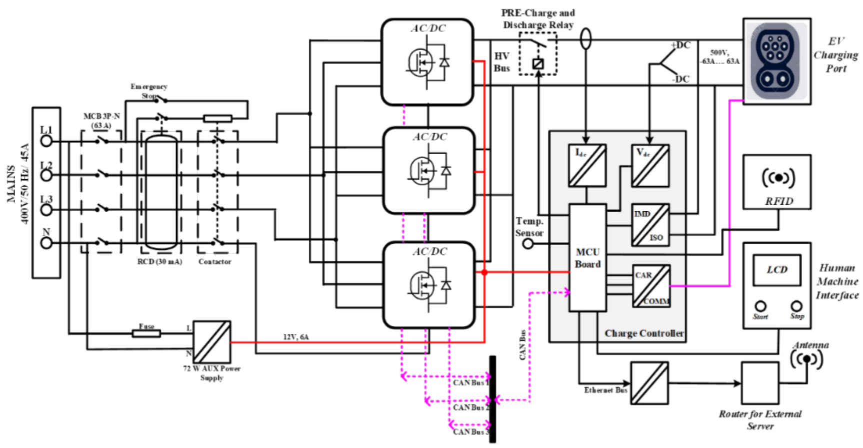


Figure 9: Internal block diagram of the 45 kW modular and scalable charger container

5.1 Proposed Charging Station Prototype

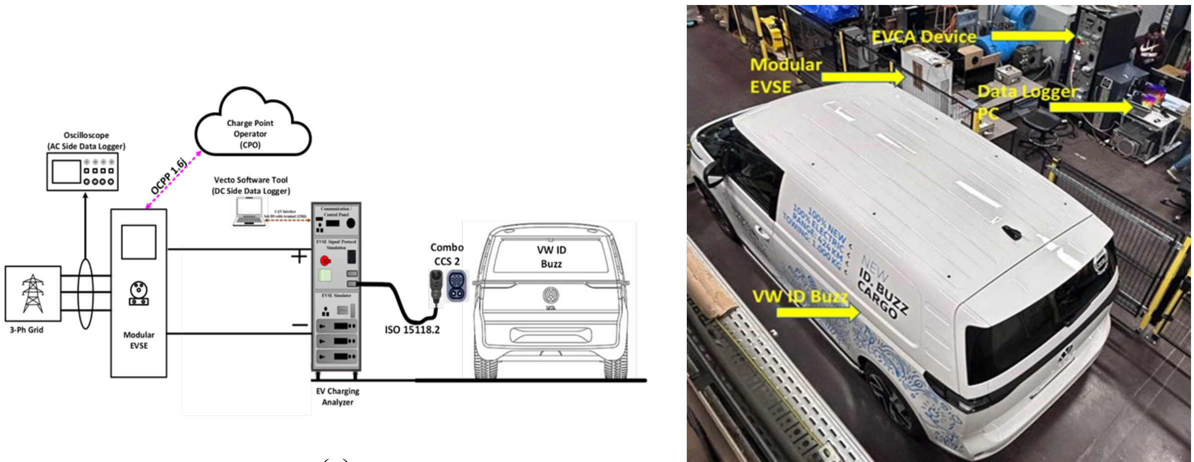
In this experimental validation, the 45kW rated DC charging station internal block diagram shown in Figure 9 is implemented with three 15kW bidirectional isolated EV charger modules. The detail design of 15kW bidirectional EV charger module is not the focus for this paper. The main contribution is modular 45kW (3x15 kW) Electric Vehicle Supply Equipment (EVSE). The EVSE container has three main sections. The first section consists of 3x15kW bidirectional AC/DC converter connected in parallel as shown in Figure 10.

Figure 10: Hardware setup of the 45kW modular and scalable charger container.;

Each of the converters has its own low-level controller, forced air-cooling fan, CAN communication port and necessary voltage-current protection devices. The maximum charging current will be around 65 A. Thus, a MCCB with 80A rupturing capacity is installed by considering more than 25% safety margin. The RCD with 30 mA is also installed according to the IEC 60364-7-722:2015 safety standard. This RCD device will protect the user from electric shock. The maximum DC output of the AC/DC converter is 500 V, thus a DC PRE-charge and discharge relay with 1000 V maximum switching voltage and 400 A rated current is inserted in series.

5.2 Experimental setup and EVSE Performance Validation

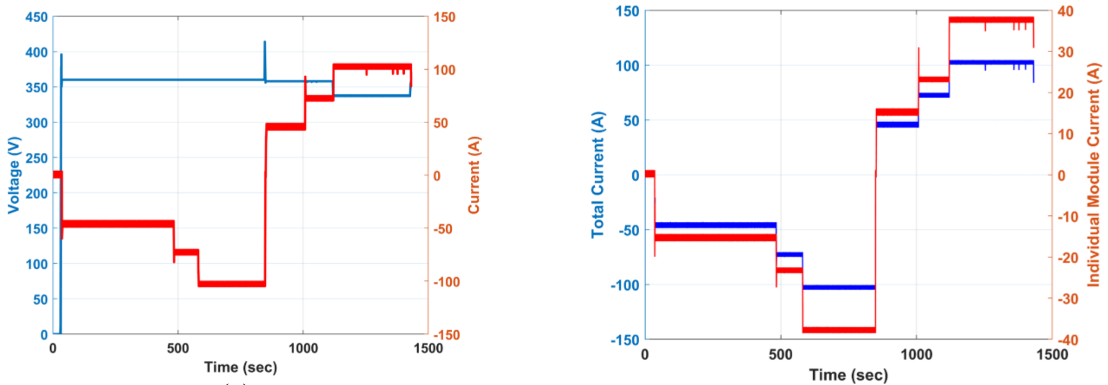
The block diagram of the overall experimental setup is shown in Figure 11 (a). The 45kW rated EVSE is implemented with a 3X15 kW EV charger module which has internal galvanic isolation.



(a) (b)

Figure 11: (a) Block diagram of experimental setup for modular and scalable DC charging station performance testing. (b) Laboratory setup for the performance test of 45 kW modular and scalable charger container with VW ID Buzz.

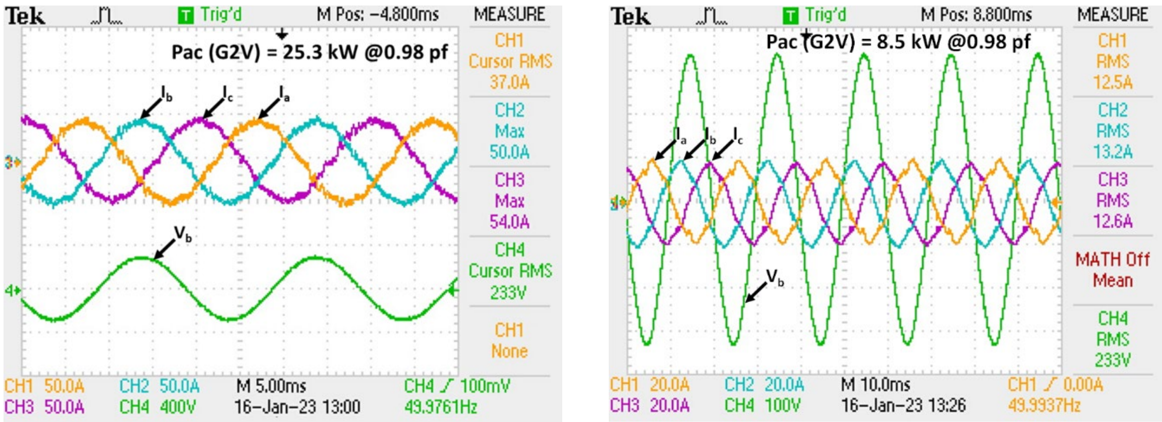
EVSE takes 3-ph AC power from the grid and provides the DC output to charge the EV battery. The EV model is a used Volkswagen ID Buzz which is fully electric van. The full specifications of the EV under test are detailed in the following section. The EVSE consists of a WiFi communication module to communicate with the CPO via OCPP 1.6j protocol to start/stop the charging or V2G session based on the RFID authorization. The electric vehicle charging analyzer (EVCA) is installed between the DC output of the EVSE and EV battery terminals. Thus, the charging power flows from EVSE to EV battery through the charging analyzer which can control, store, analyze and visualize the data. The VECTO software tool is used to operate the EVCA during the test. The ISO 15118.2 communication protocol is used to monitor and control the interaction between EVSE and EV through the control pilot pin. The battery voltage and current performance is shown in following Figure 12(a). The operator specifies the charge and discharge current setpoints on EVCA. Initially, the charging current is set to -45A, and then it is increased up to -109A. The battery voltage starts from around 360 V to increase during charging. The charging test is performed by varying the charging rate from 5 kW to 45 kW. At 5 kW charging rate, the battery absorbs around 15.7 A at 360 V. Similarly, battery takes around 73 A and 101 A during 25 kW and 45 kW charging rate. The charging current ripple is 12 A which is around 9.6% of the charging station rated current.



(a) (b)

Figure 12: DC voltage and current profile during charging and V2G test (a) Total DC voltage and current (b) Individual module current compared to total DC current during charging and V2G.

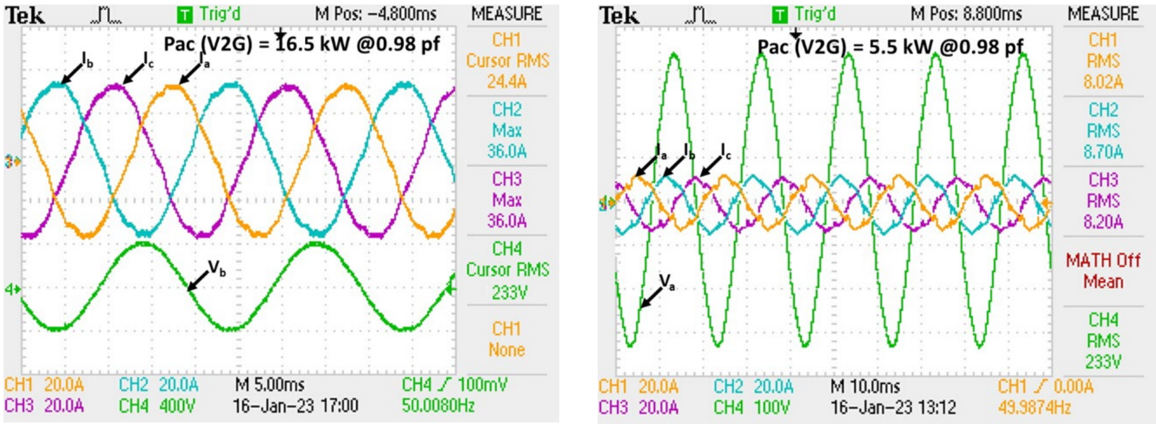
Conversely, the discharging setpoints increased from 45A to 109A. The battery voltage decreased to 340V during discharge. The EV battery discharging also tested with variable rate from 5 kW to 45 kW. The discharging current is around 45 A and 102 A at 15 kW and 35 kW discharge rate.



(a) (b)

Figure 13: AC voltage and current performance during 25 kW charging test (a) total voltage and current waveforms (b) individual module AC voltage and current waveforms

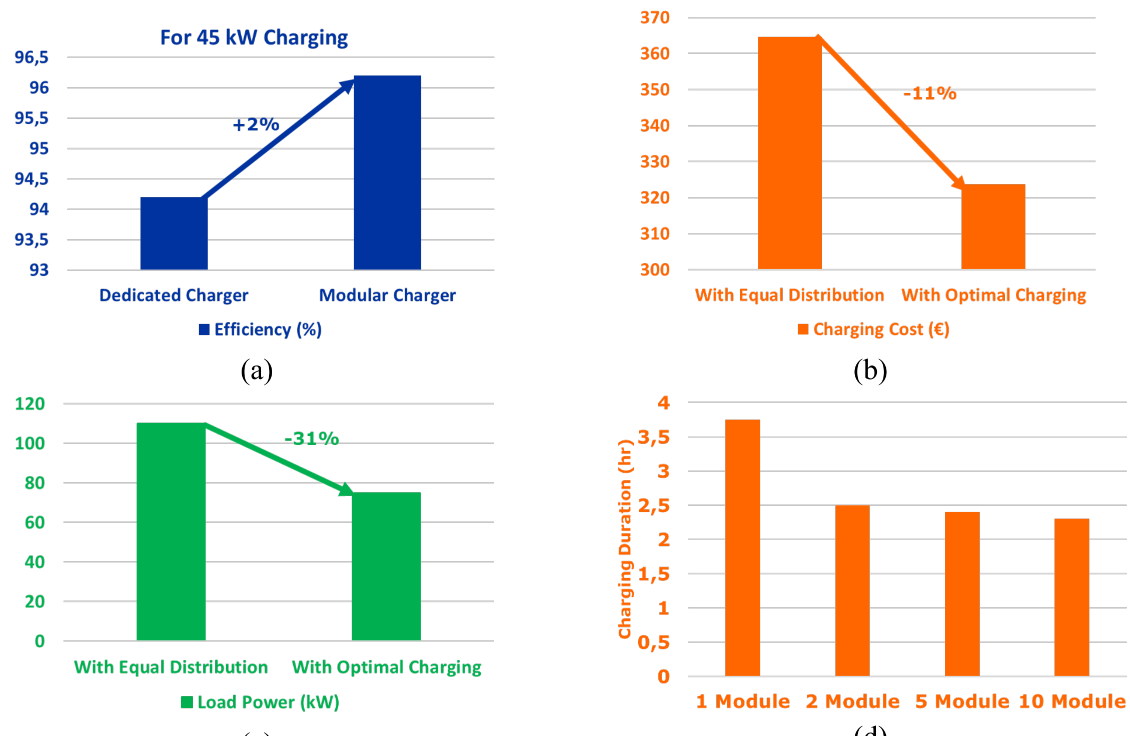
The discharge current ripple is almost the same as charging current ripple. The modular EVSE system allows the share of the charging and discharging current among 3 charging modules. The measured total and individual dc current is depicted in Figure 12 (b). The AC side performance is also investigated during charging and V2G. The EVSE container demand around 37 Arms at 233 Vac (Ph) current from the during charging the battery at 25 kW as shown in Figure 13(a). Each charging module delivered 12.5 Arms at 233 Vac (Ph) as shown in Figure 13(b). The THD of the charging current is 4.3% is estimated via FFT analysis using MATLAB/Simulink.



(a) (b)

Figure 14: AC voltage and current performance during 15 kW V2G test (a) total voltage and current waveforms (b) individual module AC voltage and current waveforms

Similarly, the charger delivers 24 Arms back to the grid during 16.5 kW V2G operation ash shown in Figure 14 (a). The individual module delivered 8 Arms during 15 kW power transfer from battery to the grid as shown in Figure 14 (b). The THD during V2G is estimated 5.7% which is higher than the charging operation. The modular DC charging system provides several benefits compared to dedicated charger modules. The modular and scalable DC charging station demonstrates significant advancements in three key performance metrics. Firstly, charger efficiency for a 45 kW charging scenario improved by 2%, increasing from approximately 94% with a dedicated charger to 96% using the modular charger ash shown in Figure 15 (a). Secondly, in terms of charging cost which depicted in Figure 15 (b), the adoption of optimal charging reduced the overall cost by 11%, decreasing from approximately €360 with equal distribution to around €320 under the optimized strategy. Additionally, the station peak demand experienced a substantial reduction due to optimal charging strategy. The peak load demand decreased by 31% as shown in Figure 15 (c) which reduced from nearly 110 kW to 75 kW .



(c) (d)

Figure 15: The operational benefits of modular DC charging station including optimal charging strategy (a) efficiency improvement compared to existing dedicated charger module (b) overall charging cost benefit (c) station peak demand comparison of modular charging station with optimal charging strategy, (d) Impact of the number of power module on the charging duration.

These results highlight the effectiveness of the modular charging architecture in enhancing operational efficiency, reducing energy expenditure, and alleviating grid stress through peak demand management. Lastly, the impact of number of charger module on the charging duration is illustrates in Figure 15 (d). The modular DC charging station reduced total charging duration from 3.8 hours (1 module) to 2.4 hours (10 modules) which is demonstrating enhanced scalability and efficiency for simultaneous multi-vehicle charging. Therefore, these achievements underscore the modular DC charger's potential for scalable and energy-efficient electric vehicle infrastructure.

6 Conclusions

This paper presented the implementation, and validation of a Modular Multiport DC Charging System integrated with an Optimal Charging Management Strategy, specifically developed for electric vehicle (EV) fleet charging hubs. The proposed system architecture emphasizes scalability, modularity, and operational flexibility to meet the high-power, multi-vehicle charging demands of fleet applications. A multi-level optimal charging management strategy was incorporated to optimize power distribution across multiple charging ports, ensuring efficient energy utilization while maintaining grid-friendly operation. According to the charging cost comparison, there is a 11% reduction in charging cost is observed when employing optimal charging strategies compared to equal distribution, underscoring economic benefits. Furthermore, around 31% decrease in peak load demand, contributing to reduced grid stress and enhanced system reliability. Experimental results from a 45kW prototype demonstrated effective power sharing among charging modules, with system efficiencies exceeding 95% during high-power operations. The charging management strategy successfully balanced load across ports, minimized idle time, and prioritized vehicles based on predefined criteria, including state-of-charge and departure schedules. Furthermore, total harmonic distortion (THD) levels remained within regulatory limits, validating the system's compliance with power quality standards. The modular architecture allows easy integration of additional ports and supports bidirectional functionalities, including V2G and V2L, enhancing the system's versatility for future smart grid applications. Overall, the proposed solution offers a technically robust and economically scalable approach for EV fleet charging infrastructure, aligning with the growing demands of electrified transportation and sustainable energy systems.

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Presenter Biography

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