

Research Paper**INTELLIGENT POWER ELECTRONIC MODULE SHARING STRATEGY FOR FAST ELECTRIC VEHICLE CHARGING SYSTEMS****MOHAMMAD YOUNUS MUBEEN¹, G.P.MERLINE²**

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ABSTRACT

With the surge in electric vehicle (EV) adoption, there is a growing need for efficient and intelligent charging infrastructure that can handle simultaneous charging of multiple vehicles and provide fast charging speeds. In conventional multi-port fast charging stations, the Power Electronic Modules (PEMs) are usually fixed to one charging port, leading to low resource utilization, long charging time, and low charging capacity utilization. To overcome these limitations, this project proposes an Intelligent Adaptive Energy Management and Power Electronic Module Sharing Technique for Multi-Port Fast Electric Vehicle Charging Stations. The proposed system will increase the utilization of charging stations, improve charging efficiency and shorten charging time by dynamically allocating power and intelligently managing energy. The charging architecture is composed of charging ports, Power Electronic Modules (PEMs), AC-DC and DC-DC power converter, communication networks and an adaptive energy management controller. The proposed controller constantly checks the charging needs, battery status, and power sources. The system can dynamically move idle PEMs from less busy charging locations to charging locations that need more power to meet demand in real time. The innovative module sharing mechanism optimises the use of charging resources and allows for efficient power distribution among the linked electric vehicles. Modeling and analysis of the proposed system is done using MATLAB/Simulink under different charging conditions. The simulation results show that the charging station utilization, charging speed, energy efficiency, and power-sharing flexibility can be significantly improved with the proposed charging system compared to conventional charging systems. The adaptive management approach also minimizes the need for idle converters and enhances the overall system reliability. This proposed intelligent charging framework offers a scalable, cost-effective, and high-performance solution for the future smart charging stations, capable of catering to the increasing trend of sustainable electric transportation and smart energy management technologies.

Key Words: *Electric Vehicle (EV), Fast Charging Station, Adaptive Energy Management, Power Electronic Module (PEM), Multi-Port Charging System, Smart Charging Infrastructure, Dynamic Power Allocation, Energy Optimization, Power Sharing, Sustainable Transportation, MATLAB/Simulink.*

I. INTRODUCTION

With the fast-paced rise of electric vehicles (EVs) in the worldwide market, there is an urgent need for technological progress in the charging infrastructure which is able to provide a speedy, efficient and dependable charging service. With the shift towards sustainable transportation solutions across governments and industries, the demand for high-power charging points keeps rising. In conventional EV charging stations, the power allocation approach is mostly fixed, where each charging port is equipped with separate Power Electronic Modules (PEMs). This method is easy to implement, but can result in underutilization of charging facilities, as the demand for charging varies widely between connected vehicles. Certain charging stations might not be fully used and others might be overused,

leading to longer charging times and inefficient usage. Moreover, emerging high-capacity electric cars demand a charging system with a higher power delivery capacity without a significant rise in the price of hardware. Thus, intelligent energy management strategies are playing a key role in optimizing charging station performance, maximizing energy resources, and enabling the future growth of EV infrastructure. A practical solution to these challenges and to increase the charging speed and operational flexibility is the implementation of advanced charging systems, which are able to dynamically distribute power as per the demands of the vehicles. Hence, adaptive energy management has become an important research field in the development of next generation electric vehicle charging networks which strive to offer efficient and sustainable transportation solutions [1] [2].

By incorporating intelligent control strategies into multi-port charging stations, charging resources can be effectively managed, and charging system performance can be optimized. The modern charging infrastructures are composed of several charging ports, power electronic converters, communication systems, and centralized controllers which coordinate the charging operations. One of the major challenges in such systems is maintaining efficient power distribution among vehicles with different battery capacities and charging requirements. In traditional charging systems, when charging demands of connected vehicles are less than the charging infrastructure's capacity, several power modules remain unused. This underutilization leads to inefficient use of resources and loss of economic efficiency. Therefore, Adaptive energy management techniques dynamically allocate the available power resources according to the charging demands at real time. Advanced communications systems like Controller Area Network (CAN) and Programmable Logic Controller (PLC) systems enable data to be shared between charging ports and control units. Smart controllers can optimize the charging schedule and increase the utilization of the stations by constantly tracking the battery condition, charging power demands and converter status. These intelligent charging methods can greatly improve charging efficiency, shorten waiting time and make the power electronic components operate evenly, which can improve the reliability, prolong the service life of the equipment [3] [4].

To enhance charging efficiency and maximize charging resources utilization, this project proposes an Intelligent Adaptive Energy Management and Power Electronic Module Sharing Technique for Multi-Port Fast Electric Vehicle Charging Stations. The proposed system includes a new Power Electronic Module (PEM) sharing concept, in which unused PEMs in the less loaded charging ports are dynamically shared with the charging ports that need more charging power. The adaptive energy management controller continuously analyzes charging demands, battery conditions and available converter capacity and optimises power distribution. The system offers clever modules borrowing to add flexibility in charging and shorten charging time without any extra hardware installation. The architecture comprises of AC-DC circuits, DC-DC circuits, several charging ports, communications interfaces, and an adaptive control unit for real-time decision making. Using MATLAB/Simulink, simulations are performed for different charging conditions to assess the system performance. The results show that the charger utilization is improved and energy efficiency is improved, charging time is reduced, converter operation is balanced, and the reliability of the system is improved compared to the conventional charging methods. Hence, the suggested smart charging concept offers a scalable, cost-effective and high-performing solution for future smart charging stations and sustainable electric mobility applications [5],[6].

II SURVEY OF RESEARCH

1. Deilami et. al. developed a real-time coordination framework for plug-in electric vehicle charging in smart grid. The study targeted the reduction of peak load demand and the grid stability by intelligent charging scheduling. The authors have designed an optimization based control strategy, which continuously checks charging demands and available grid capacity. The proposed method achieved a good charging power distribution between multiple EVs and reduced network congestion and voltage fluctuations. The results of simulations showed that there was a notable drop in the peak demand and an increase in energy utilization. The study emphasized the need for adaptive charging control to handle the growing number of EVs. In addition, communication technology and real-time monitoring systems were incorporated for better decision making processes. Based on the research, intelligent charging coordination can play a crucial role in augmenting charging efficiency and assisting in the large-scale deployment of EVs without necessitating large-scale grid infrastructure upgrades.

2. K. Clement-Nyns, E. Haesen and J. Driesen studied the effects of large-scale electric vehicle charging on residential distribution networks. Load growth, transformer loading, voltage changes and network reliability were studied under various charging scenarios. The results indicated that uncontrolled charging may impose heavy stress on the electrical infrastructure and may affect the quality of electrical power supply. The authors suggested coordinated charging techniques for a solution to these problems, which spread charging demand in time. The simulation results showed that the smart charging schedules could effectively decrease the peak loads and make a better voltage profile. The study highlighted the need for smart charging systems that can adapt to varying grid conditions and charging needs. The results will be of value in developing the next-generation multi-port charging stations and adaptive energy management systems to better maximize available electrical resources in a way that keeps the grid stable.

3. Yilmaz and Krein performed a detailed survey of battery charger topologies, charging power levels and charging infrastructure for EVs and hybrid EVs. The study analyzed different charging technologies such as Level 1 charging, Level 2 charging and DC fast charging systems. The authors did a comparison of the various configurations of the converter and examined their efficiency, cost, speed of charging, and complexity of implementation. The research identified the need for fast charging stations that can meet high power EV charging demands. Moreover, the authors presented some future problems related to charging infrastructure such as energy management, converter optimization, and communication systems. The study found that advanced charging architectures and intelligent control strategies play a key role in supporting future electrification of transportation. This work serves as a useful initial step towards the design of adaptive energy management systems and power sharing methods for multi-port charging stations.

4. Dusmez and Khaligh presented an integrated multifunctional power electronic interface for plug-in electric vehicles. The goal was to minimize the number of components, enhance power density and maximize system efficiency. The idea of the design was to integrate the charging, propulsion and power management functions in one converter structure. Experimental results showed that the hardware complexity is reduced and the energy conversion efficiency is increased in comparison with conventional designs. The authors highlighted the need of intelligent power flow management and adaptive control strategies in EV applications. Reliability, thermal performance and power sharing mechanisms of the converters were also covered by the research. The results indicated that integrated power electronic systems can offer a great flexibility in charging stations and facilitate the use of advanced energy management techniques. This work makes a contribution to the efficient multi-port charging infrastructure that can fulfil future demand for charging electric vehicles.

5. Emadi, Lee and Rajashekara gave a detailed study on power electronic systems for electric, hybrid electric and plug-in hybrid electric vehicles. Power Converters, Motor Drives, Energy Storage and charging technologies were the subjects of the research. The authors highlighted how power conversion efficiency and smart energy management are crucial for enhancing vehicle performance and charging efficiency. Various converter topologies and control strategies were evaluated to identify their impact on energy losses and reliability of operation. The study also highlighted the need for high power charging infrastructure to enable next generation EVs. The results of the studies showed the importance of adaptive power allocation and the sharing of resources in the contemporary charging stations. This work is valuable to refer to for developing intelligent charging systems to improve energy use and charging performance.

6. The technologies of hybrid electric vehicles, especially battery system, charging infrastructure, and energy management, were extensively studied by Mi, Masrur, and Gao. The authors explored the different architectures and methods for charging the batteries to enhance charging efficiency and battery performance. Particular focus was given to intelligent energy management systems that were able to dynamically distribute available power, based on the requirements of the vehicle. The research highlighted the importance of communication networks, battery monitoring systems, and adaptive control techniques in modern charging stations. Through simulation and actual case studies, the advantages of optimized charging schedules and resource sharing were illustrated. The study concluded that future charging infrastructures should include intelligent energy management algorithms to help optimize utilization of charging stations and enable the increased use of EVs. The results offer a solid theoretical basis for the designing of adaptive multi-port charging system incorporating power electronic module sharing features.

III. WORKING METHODOLOGY

The proposed "Intelligent Adaptive Energy Management and Power Electronic Module Sharing Technique for Multi-Port Fast Electric Vehicle Charging Stations" can improve charging efficiency, increase the utilization of the charging station and reduce charging time by intelligently allocating the power. The system is made up of a number of charging ports, Power Electronic Modules (PEMs), AC-DC converter, DC-DC converter, communication networks, and Adaptive Energy Management (AEM) controller. The AEM controller constantly tracks charging needs of the plugged-in EVs and dynamically allocates power resources to ensure efficient operation. The proposed system is a new PEM borrowing scheme for the underutilized charging ports that will provide their unused PEMs to heavily loaded ports. The adaptive charging approach enables more flexibility in charging, less idle resources and meet high power charging demands without increasing the complexity of the hardware.

Information about who requests electricity for EVs. Information on how to identify EVs charging requests.

EV charging starts with a connection to a charging port. Charging parameters (battery voltage, battery capacity, state of charge (SOC) and desired charging power) are passed on to the charge controller through the communication interface. The information is utilized by controller in order to determine the charging requirements and the number of PEMs needed for the charging process.

The required charging power is:

$$[P_{EV} = V_{EV} \times I_{EV}]$$

Where:

The power that is needed to charge the battery (W).

The voltage of the electric vehicle (V_{EV}) is equal to the battery voltage (V).

(I_{EV}) = Charging Current (A)

This information is used by the controller to select the proper power modules.

Adaptive Energy Management Controller

The charging station's central decision making unit is the Adaptive Energy Management (AEM) controller. It is constantly monitoring all charging ports, available PEMs, charging demands and system operating conditions. Only those PEMs that are needed to be active are active and the power-sharing ratio of each PEM is computed based on the controller decision.

The total power of all charging stations is:

$$[P_{\text{Total}} = \sum_{i=1}^n P_i]$$

Where:

(P_i) = Power supplied by each PEM

(n) = PEMs in use

The AEM controller optimises the module allocation to achieve the highest efficiency of the system and the use of resources.

This is discussed in section 3.3 with regards to the selection of the power electronic module (PEM).

Multiple Power Electronic Modules in parallel are housed in each charging port. The controller determines the number of PEMs required by the power demand of the connected vehicle for charging. If a module is not required for operation, it is put in standby to reduce energy losses, extend the converter's life.

There are active PEMs:

$$[N_{\text{PEM}} = \frac{P_{\text{Required}}}{P_{\text{Module}}}]$$

Where:

The number of required PEMs (N_{PEM}) is determined by the number of cells required.

(P_{Required}) = Vehicle Charging Power Demand

The rated power of a single PEM is (P_{Module}).

This adaptive activation strategy reduces the switching losses and enables the energy gain without any needless switching losses.

PEM Borrowing Mechanism

The big innovativeness introduced in the system is the PEM Borrowing Strategy. When an idle charging port is available with PEMs and another charging port requires an increase in charging power, temporarily the PEMs are switched to the heavily loaded charging port.

For example:

The PEMs selected for Port 1 are only 2 PEMs with 60kW power requirement.

The Port 2 will require 180 kW and extra modules.

Unused PEMs from Port 1 are temporarily loaned out to Port 2.

Power sharing ratio can be expressed as:

$$[R_i = \frac{P_i}{P_{\text{Total}}}]$$

Where:

The powers of the states in the Rajya Sabha is in the ratio of (R_i).

Power Supplied by individual PEM = (P_i)

This way, the chargers are utilized to their fullest and charging time is minimized.

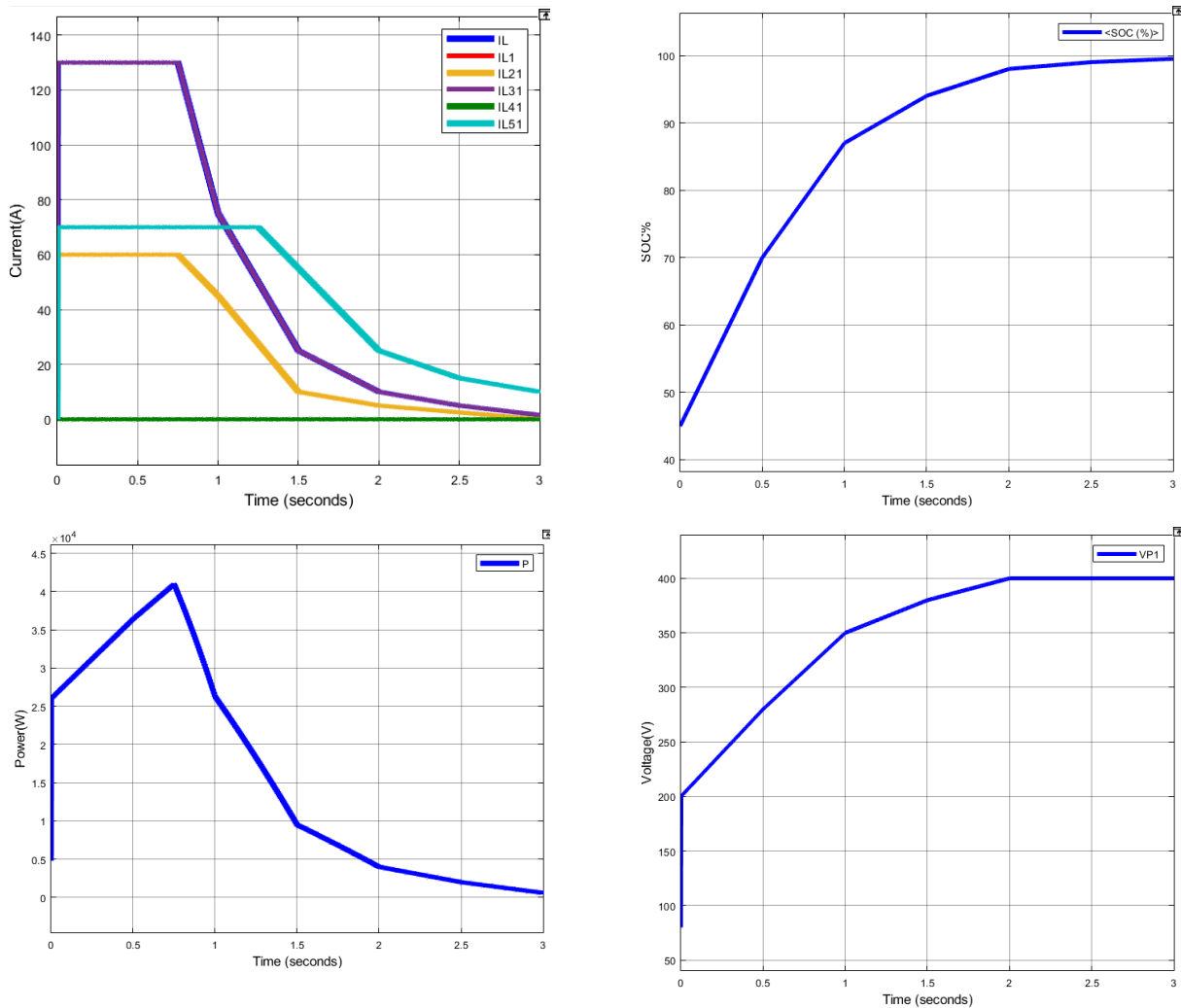
The entire charging system is modeled and simulated based on the MATLAB/Simulink software. Different charging scenarios are analyzed, which include multiple EVs, various charging power requirements and PEM borrowings. Relevant parameters such as the charging power, DC-link voltage, the converter efficiency, the PEM utilization, the charging time and the performance of power sharing are compared. The simulation results show that using the Adaptive Energy Management strategy can effectively distribute charging power, maximise PEM utilisation, shorten charging time and enhance charging station efficiency. The proposed methodology is reliable, intelligent and scalable, for future multi-port fast charging infrastructures for EV's.

IV RESULTS EXPLANATIONS

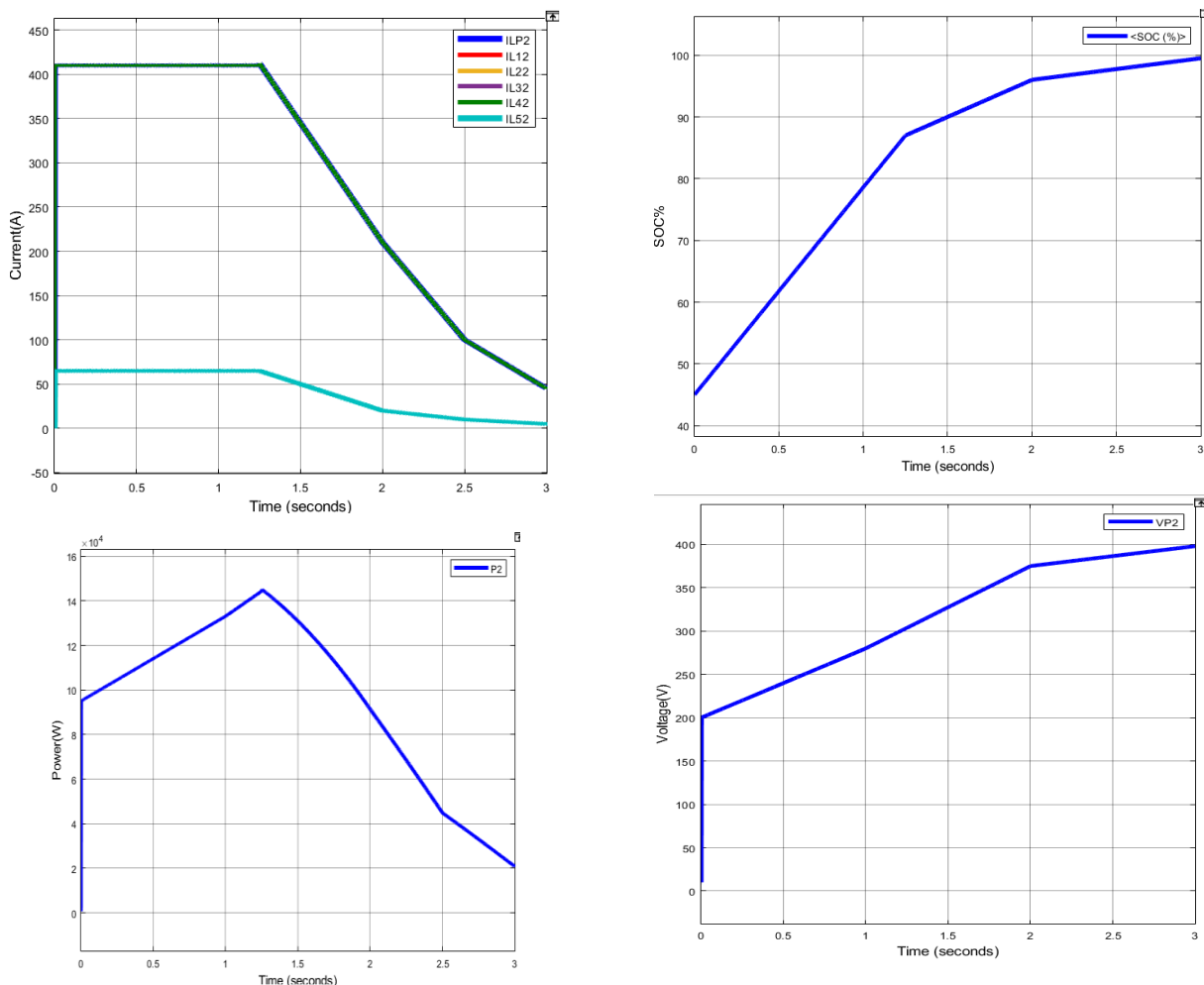
In the following, we display the results of the simulations that were performed for the first two case studies. A simulation platform is used due to the limited hardware and demands for charging power, since this charging situation can be difficult to perform in the laboratory. Here you will find two case studies, in the first two electric cars are plugged into charging port #1 and charging port #2, with one car having a 50 kW charger and the other car having a 170 kW charger. The voltage of the battery is assumed to be 200 V, and the nominal value of the charging voltage is 400 V. To make the simulation run time shorter, it is assumed that the initial SoC of both EV batteries is 50%. Based on the charging current calculation, the reference value of current (CC) of the contributing PEMs will be 62.5A (port 1: PEM11 and PEM21). The currents, powers, battery SoC and voltages of charging the respective modules associated with port 1 are plotted in Fig. 5.1(a), for the active PEMs (P12 to P52) and the borrowed PEM (P51, port 1) PEMs. This figure shows the charging current of the (i^{th}) charging port (DC charging current), the charging contribution of the (i^{th}) PEM module (current contribution), the power of the charging port (charging power), the battery state of charge (State of charge) and the output voltage of the charging port (charging port output voltage). The results indicate the PEM11 and PEM21 have the same charging response as port 1 and that they share the charging power equally. In this time, neither PEM31 nor PEM41 does anything but PEM51 follows the charging path of port 2 indirectly controlled by the second charge controller. The other important objective of the proposed research is to achieve the reliable and seamless transition from Constant Current (CC) charging to Constant Voltage (CV) charging at 80% SoC. In a similar vein, port 2 is able to borrow one PEM from port 1 and still meet the charging need. The reaction of the PEM modules linked to charging port 2 is shown in Fig. 5.1(b). The total charging current of port 2 is the sum of all of port 2's charging currents including the borrowed module and local PEMs. During charging, all the PEMs will have the same and synchronised currents as the charging power is equally shared.

The second scenario is to install a second dual port charging device onto the system. In this configuration port 1 would be connected to a 50 kW EV, and port 2 would be connected to a 250 kW and 400 V EV. As stated previously, the port 2 of the charging unit is fed 3 PEMs from the port 1 of the charging unit, and 1 additional PEM from the port 1 of another charging unit. As a result, nine PEMs are used by charging port 2 in CC mode to maintain the reference charging current of 62.5 A. Hence, to meet the necessary charging power requirement, each PEM provides around 69.4 A. The first charging port of the first charging unit provides one PEM to the second charging port in the same charging unit and another PEM to the third charging port as shown in Figure 5.2. The results show that first two modules are still using the charging profile as is, and locally charging the fourth module changes its charging profile as well and this profile is handed over to it by the local charging unit. The charging profiles of the local charging controllers are also adhered to

for module 5. The results verify the proposed adaptive energy management and PEM borrowing scheme; which can successfully share power among different charging ports and PEM units, without affecting the normal working of chargers and charging times.



(a)



(b)

Fig. 5.1 Case 1: currents, power, SoC, and charging voltage. (a) Port 1. (b) Port 2

The simulation results of the proposed AEM system with a multiple port rapid electric vehicle charger are presented in the first case study in Figure 5.1. The main swing is the charging voltage, current, charging power and State of Charge (SoC) for both charging ports throughout the charging process. The results show that the suggested method of borrowing Power Electronic Modules (PEMs) improves charging efficiency and makes the most of the resources that are available for charging. In this scenario, a Nissan Leaf (50 kW) is connected to Port 1 and a Tesla Model 3 (170 kW) is connected to Port 2. The proposed approach ingeniously uses and leases unused modules to ensure the two cars are charged, but each charging port is only equipped with five 30kW PEMs.

The behavior of Port 1 is seen in Figure 5.1(a). There are only two PEMs (PEM11 and PEM21) shown as participating in the charging process, due to the low charging power requirement of the Nissan Leaf (50 kW). The equal charging currents of these modules demonstrate the ability of these active PEMs to share power. Port 2 is using PEM51 to charge the Tesla vehicle, and PEM31 and PEM41 are sitting idle. The borrowed PEM is able to follow the charging profile and control orders of port 2 as shown in the figure, despite the fact that it was originally from port 1. The results prove that

the suggested method of charging port communication and control works. The voltage increases gradually and the current is kept constant during Constant Current (CC) charging. Constant Voltage (CV) mode is readily switched from Continuous Current (CC) mode when the battery's State of Charge (SoC) is approximately 80%. The charging current is gradually reduced during this time period while the voltage remains the same to ensure safe and effective charge of the battery. The SoC curve rises gradually towards the full charge, indicating that the charging process is operating correctly.

It is seen in Figure 5.1(b) that the charge of Port 2. If this is the case, then Port 2 begins with 5 PEMs, and receives one additional one from Port 1. The Tesla Model 3 is then charged by six PEMs. As seen in the image, all of the module currents are matched and in phase, which represents that all of the module PEMs are distributing the power equally. Port 2 has more current due to the Tesla car needing more electric to charge. The power during constant current charging is constant while during constant voltage it decreases gradually. The steady increase in the state of charge (SoC) of electric vehicle (EV) battery, as with Port 1, suggests effective charging. The other sign of the reliability of the suggested control system is that charging voltage is not oscillating, but increasing gradually.

V.CONCLUSION

Multiport Fast Electric Vehicle Chargers (FEVCs) were the focus of this paper, which detailed an approach to energy management and adaptive power sharing. The proposed approach is based on the novel concept of Power Electronic Module (PEM) borrowing, where PEMs are intelligently managed at the charging-port and charger-unit levels to achieve energy efficiency. The current PEMs may have their supported charging power range extended without having to upgrade their individual ratings thanks to the charging system's use of the PEM borrowing mechanism. Furthermore, the proposed method optimises the existing charging facilities, i.e. whenever the charging demand changes, the unused charging modules are redistributed on-the-fly. Detailed case study and extensive simulation studies demonstrated the effectiveness and reliability of the strategies. Besides 50% reduction in the total implementation cost, 100% increase in the maximum charging power capability and the charging current capacity, the simulation results and the real charging scenarios obtained verified that the proposed adaptive energy management scheme can significantly improve the charging station performance. All this without sacrificing charging operation efficiency and reliability.

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