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A Bidirectional V2G Charging Point Operator with Model Predictive Control for Energy Trading Platform

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Executive Summary

This paper propose a Bidirectional V2G charging system Operator management with Model Predictive Control. This management system will control bidirectional charging station to absorb excessive energy from PV Station the same grid and return such energy to another G2V charging station in the suitable period to avoid the load current not to over grid limitation through MQTT protocol. The Operator management system has developed in Node Red Platform with specific constraint and calculate optimum charging current by MPC Algorithm with communication MQTT Protocol through internet network to charging station. In this paper, the system have been developed the 400 V 3 Phases 15 kW bidirectional charging station and modified electric vehicle with 17.39 kW battery capacity with capability to perform V2G mode. The testing result found that the Bidirectional V2G charging system Operator management can control the bidirectional charging station to absorb power form PV Station and return such power to other G2V charging station in the suitable time effectively. The grid with Bidirectional V2G charging system Operator managementhave more stability in overload protectionthan the grid without any charging station control.

Keyword

Electric vehicle, DC Charging Technology, V2G (Vehicle to Grid), Energy Storage System, Energy Management

1. Introduction

The integration of Vehicle-to-Grid (V2G) technology into modern energy systems presents significant opportunities for improving grid stability, optimizing energy use, and supporting renewable energy integration. This article introduces a bidirectional V2G charging system operator powered by Model Predictive Control (MPC) to enhance the capabilities of energy trading platforms. The proposed system enables electric vehicles (EVs) to participate actively in energy trading by efficiently managing bidirectional energy flows between EVs and the grid. Utilizing MPC, the system predicts energy demand, price fluctuations, and grid conditions in real-time, allowing for dynamic and optimized charging and discharging strategies. These strategies are tailored to user preferences and grid requirements, ensuring both economic and operational benefits. Key findings from the study demonstrate the system’s ability to Lower energy costs for EV users through smart energy trading, to improve grid performance by balancing energy supply and demand and Enhance the adoption of renewable energy by mitigating intermittency issues. This work highlights the strategic role of MPC-based V2G systems in creating sustainable, cost-effective, and reliable energy ecosystems. The findings are particularly relevant for stakeholders in the EV industry, grid operators, and policymakers aiming to advance smart grid solutions and energy trading innovations. The platform supports seamless integration of V2G technology into smart grids, providing a scalable and flexible solution for energy trading. Experimental results demonstrate the system's ability to reduce energy costs for EV users, improve grid performance, and facilitate renewable energy integration. This research highlights the potential of MPC-driven V2G systems as a key enabler for future sustainable energy ecosystems. The illustration abstract of this paper are shown in Fig.1 which compose of concept of CPO for V2G, Bidirectional Power Converter, V2G Charging System, Result and Energy Trading

Platform respectively. In this diagram, the communication protocol standard such IEC61851, ISO15118 are used to communicated between EV and EVSE. The Charge Point Operator and Aggregator use to control the charge point topology and energy management via back end protocol. In order to manage distribution system to get efficiency, reliable and stability, DSO/TSO need to plan and control EV load flow OSCP and Open ADR and IEEE 20230.5.

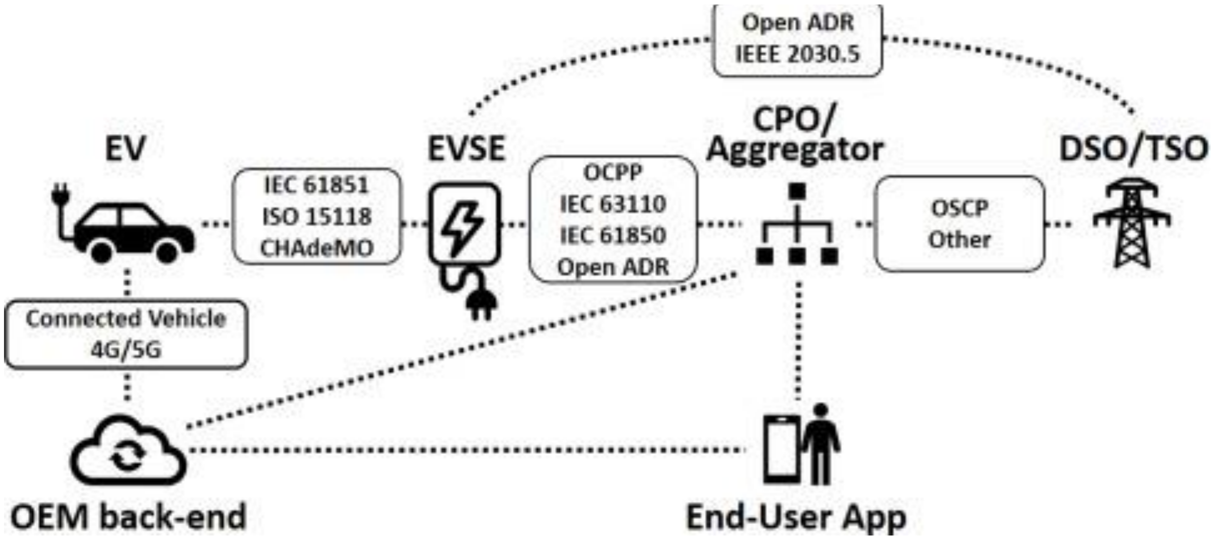

Fig. 1 Charging Point operator to Control EV Charging

2. Theory and Literature review

2.1 An Electric Vehicle Charging Station

An Electric Vehicle Charging Station (EVCS) is a critical component of the electric mobility infrastructure, providing the necessary electrical energy to recharge the batteries of electric vehicles (EVs). These stations come in various configurations, including Level 1 (slow charging), Level 2 (fast charging), and DC fast charging (rapid charging), each differing in terms of charging speed and power output. The integration of EVCSs into the power grid presents challenges related to demand management, power quality, and grid stability, especially during peak charging times. To address these challenges, smart charging strategies are employed to optimize charging schedules, balance load distribution, and minimize energy costs. Furthermore, advancements in bidirectional charging, such as Vehicle-to-Grid (V2G) technology, allow EVs to not only consume energy from the grid but also supply energy back to it, thereby enhancing grid resilience and supporting the adoption of renewable energy sources. Bidirectional Electric Vehicle Charging Stations enable both Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) functionalities, allowing electric vehicles (EVs) to dynamically interact with the power grid. In G2V mode, the EVs draw power from the grid to charge their batteries, while in V2G mode, the stored energy in the EV batteries can be fed back into the grid to support energy demand or stabilize the grid during peak load times. This bidirectional energy flow enhances grid flexibility, promotes efficient energy use, and can contribute to the integration of renewable energy sources by balancing supply and demand. V2G technology also enables energy storage solutions at a distributed scale, where aggregated EV batteries act as a virtual power plant, providing ancillary services such as frequency regulation and voltage support. The implementation of such systems requires sophisticated control strategies to manage charging schedules, battery health, and grid conditions, ensuring a balance between vehicle availability and grid needs.

2.2 Bidirectional Converter

In Fig.2 show that the concept of V2G Bidirectional EV Charger which can consume energy and also generate electricity back to the grid via battery on electric vehicle. For this situation, V2G EV can manage energy according to the behavior of customer and use the economic electricity rate to adapt the load profile for receive the high efficiency, reliability and economical aspect.

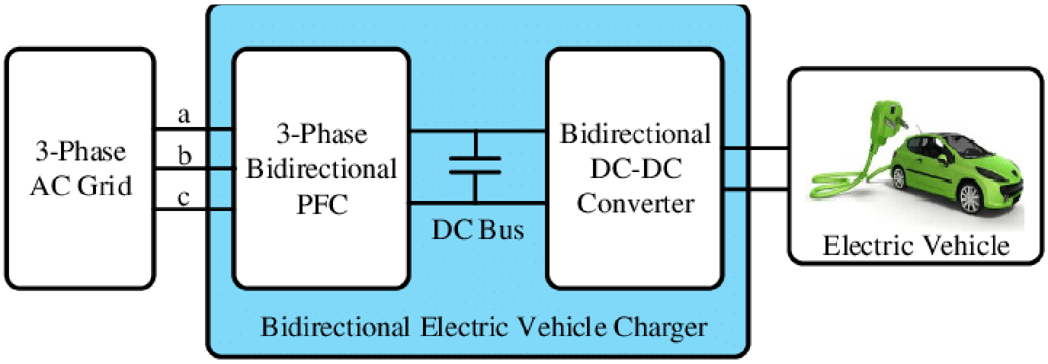

Fig. 2 Bidirectional Power Converter

The Fig 3 Show the V2G Charging System which compose of Battery, Cooling System, Battery management system, on board charge, connector, bidirectional converter and utility power system respectively.

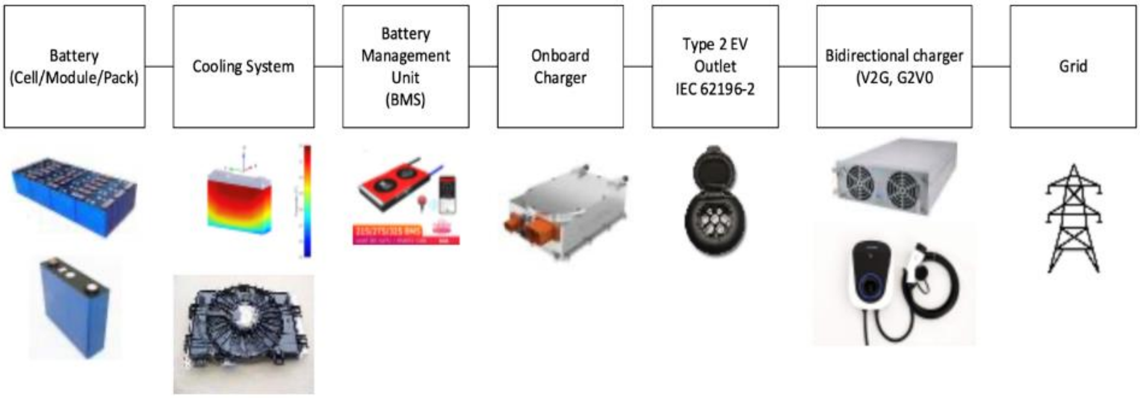

Fig.3 V2G Charging system

A bidirectional power variable L device is used in the development of a single-use charging station. Two directions in this research were used, Bidirectional Converter Module Model BEG75050, which required Control the operation of equipment through CAN BUS communication. In order to send a command to the device for varies the power via Charging Management System. The specification of Bidirectional Power Module is shown in Table 1.

Table 1 Specification of AC-DC Bidirectional Converter

AC to DC Mode	AC Input	Input voltage&current range	400Vac, 3L+PE;0-30A
		Input voltage/frequency range	260 – 485 Vac, 45-65 Hz
		Power factor	>0.98 Full load output power of @50-100%
		THD	< 5% Full load output power of @50-100%
	DC Output	Rated power	15 kW
		Voltage and current range	150-750 Vdc, 0-50 A
		Voltage stabilized accuracy	< +-0.5%
		Current stabilized accuracy	< +-1% (output power in 20-100%)
		Efficiency (max)	> 96%
DC to AC Mode	DC input	DC input voltage and output power	From 300 to 750 Vdc, output power is 15 kW Lower than 300 V will do the protection
		Max input current	50 A
	AC output	Output AC voltage and output power	From320 to 485 Vac, output power is 15 kW
		Rated power and current	15 kW/23A
		Output AC frequency	50 Hz/60 Hz
		THDi	< +-5%
		Output power factor	User Setting, 0.8-1, -0.8- -1
		Efficiency (max)	>96%

2.3 The communication Equipment and Protocol for EVSE

The V2G (Vehicle-to-Grid) server utilizing HQ MQTT, Node-RED, Raspberry Pi, CAN Bus, and SPI operates as an integrated system to manage communication and control between electric vehicles (EVs) and the power grid. Here's an overview of how each component functions within the V2G setup:

1. MQTT Protocol: The High-Quality MQTT (HQ MQTT) serves as the lightweight messaging protocol that facilitates real-time communication between the various components of the V2G system. It allows the server to publish and subscribe to messages from EVs, charging stations, and other devices, enabling efficient data exchange and control commands.

2. Node-RED: Node-RED is a visual programming tool that orchestrates the entire workflow of the V2G server. It allows users to create flows that define how data is processed, monitored, and controlled. Through its graphical interface, users can easily integrate various data sources, manage charging operations, and set up alerts for system events.

3. Raspberry Pi: The Raspberry Pi acts as the central processing unit of the V2G server, running both Node-RED and the MQTT broker. Its compact size and affordability make it suitable for deployment in various environments. It handles data processing, communication, and control tasks, ensuring smooth operation of the entire system.

4. CAN Bus: The Controller Area Network (CAN Bus) is a robust communication protocol used to connect the EVs to the V2G server. It facilitates communication between the vehicle's onboard systems and the server, allowing for the monitoring of battery status, state of charge, and other essential parameters. This data enables the server to optimize charging and discharging operations based on real-time conditions.

5. SPI (Serial Peripheral Interface): SPI is utilized for high-speed data transfer between the Raspberry Pi and peripheral devices, such as sensors or additional modules in the system. It enables quick communication and control of devices that require fast data exchange, ensuring efficient processing of signals related to the EV's performance.

In operation, the V2G server monitors the state of charge of connected EVs through the CAN Bus. Based on this information and real-time grid conditions, Node-RED determines optimal charging and discharging schedules. The server can command EVs to discharge power back to the grid during peak demand or charge during low-demand periods, facilitating energy management and grid stability. The MQTT protocol ensures that all components communicate efficiently, while the Raspberry Pi provides the computational resources necessary to run the system seamlessly. By integrating these technologies, the V2G server effectively manages the interaction between EVs and the power grid, enhancing energy efficiency and supporting the transition to sustainable energy systems as shown in Fig. 5

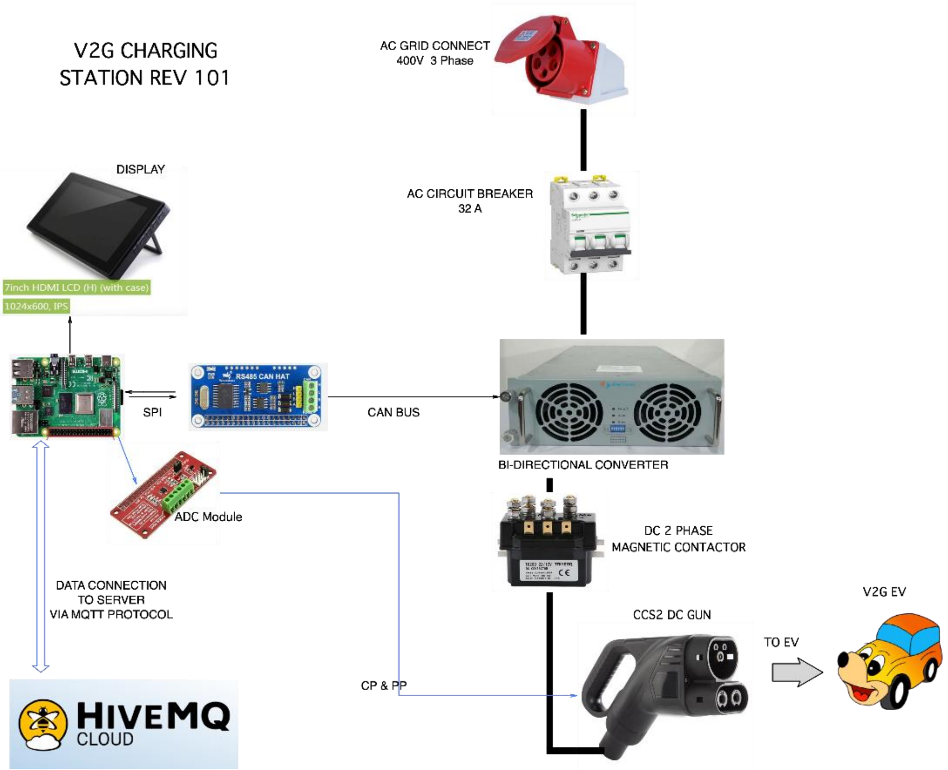

Fig.4 Diagram of V2G Charging Station with MPC Control

The communication protocol for Electric Vehicle Charging Stations is crucial for enabling interoperability and efficient interaction between electric vehicles (EVs) and the charging infrastructure. Three key standards govern this communication: ISO 15118, IEC 61851, and DIN 70121. ISO 15118 defines a bidirectional communication interface that supports advanced features like Plug & Charge, where authentication and billing occur automatically, as well as Vehicle-to-Grid (V2G) functionalities. IEC 61851 provides the fundamental requirements for conductive charging, covering the electrical safety aspects and signaling between the EV and the charging station to establish proper current flow and charging parameters. DIN 70121, meanwhile, outlines communication protocols for direct current (DC) charging, focusing on high-power charging scenarios. Together, these standards ensure a reliable and secure exchange of information, enabling smart charging, grid integration, and user-friendly experiences in EV charging.

2.4 Charging Management system with model predictive control

An Electric Vehicle Charging Management System (EV CMS) is designed to optimize the operation of electric vehicle charging infrastructure by managing, monitoring, and controlling charging stations. It coordinates charging schedules, balances energy loads, and integrates with energy management systems to prevent grid overload and minimize energy costs. The system can prioritize charging based on factors like energy prices, demand, and user preferences, while also collecting data for maintenance, billing, and analytics. The Open Charge Point Protocol (OCPP) is a communication standard that facilitates interoperability between charging stations and management systems. It allows charging stations from different manufacturers to communicate with a central management platform, ensuring compatibility and flexibility in expanding charging networks. OCPP supports functions such as remote monitoring, firmware updates, reservation of charging spots, and load management. By standardizing the communication interface, OCPP enables a scalable, vendor-neutral approach to managing charging stations, making it easier for network operators to adopt and integrate new charging technologies. In order to control power transfer of each charging station, Model Predictive Control (MPC), a control technique that can consider various constraints and predict future system behavior. Using currently available information This approach helps optimize decision-making on charging processes and returning energy to the grid. Model Predictive Control (MPC) is a sophisticated control strategy used for managing Electric Vehicle (EV) Charging Stations by predicting future system behavior and optimizing charging decisions accordingly. The fundamental principle of MPC involves three main steps: prediction, optimization, and control action as shown in Fig.5.

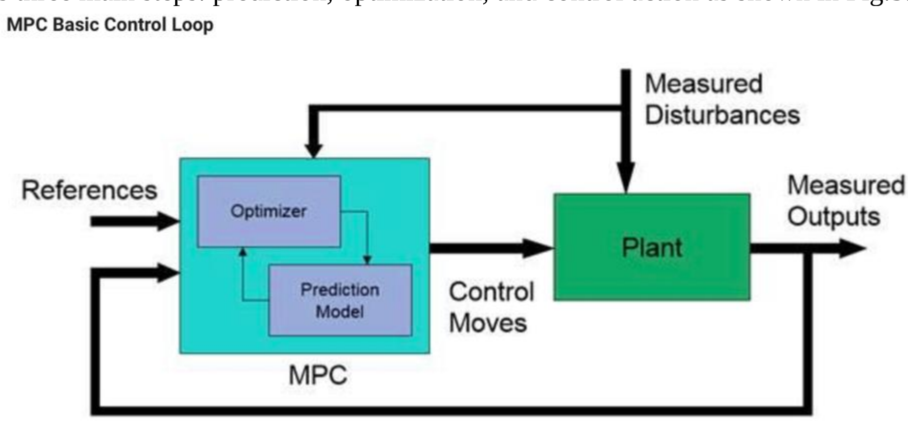

Fig.5 Principle of MPC

1. Prediction: The MPC algorithm uses a mathematical model of the charging system, which includes EV characteristics, charging station dynamics, and grid conditions. It predicts the future states of the system over a finite time horizon based on current measurements and estimated future inputs, such as energy demand, electricity prices, and grid constraints.

2.Optimization: With the predicted system behavior, MPC formulates an optimization problem that minimizes a predefined cost function, which may include objectives like reducing electricity costs, minimizing grid impact, or maximizing charging efficiency. The optimization is subject to constraints such as charging power limits, battery state-of-charge, and grid regulations.

3.Control Action: Once the optimal solution is found, the first control action in the optimized sequence is applied to the charging system. The process then repeats at each control step, using updated system measurements and forecasts to account for any disturbances or uncertainties as shown in Fig.6. MPC's ability to incorporate future predictions and adaptively optimize charging strategies makes it particularly effective for EV Charging Station Management, allowing for smart scheduling, load balancing, and integration of renewable energy sources.

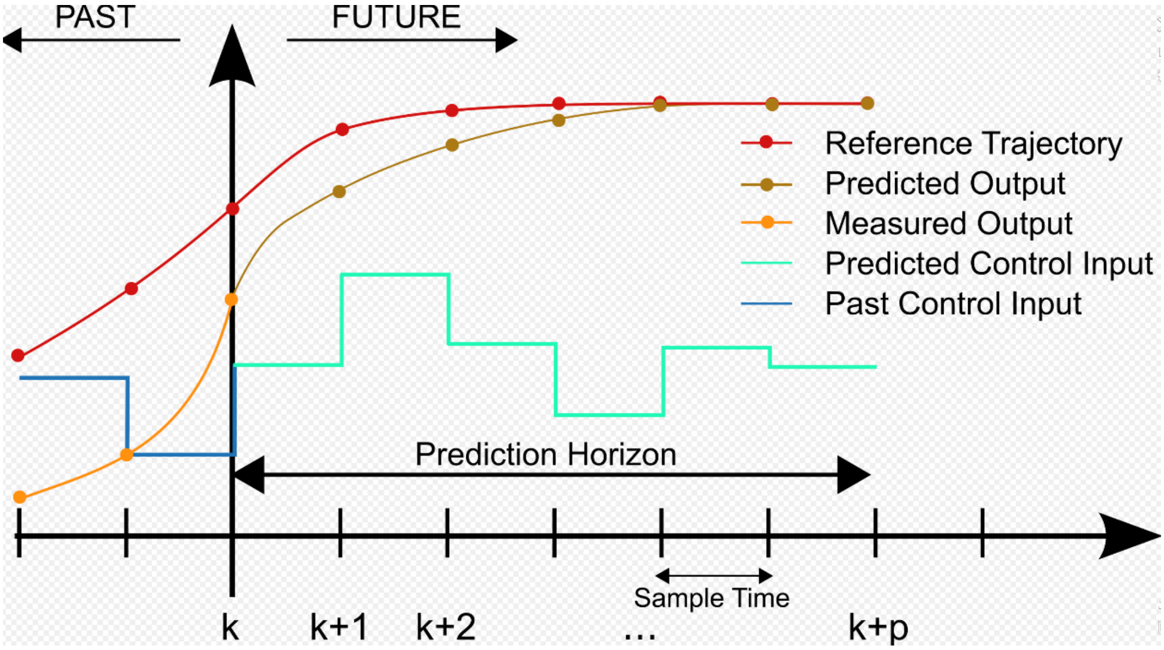

Fig.6 Principle of prediction Control

3. Design and Experimental

A design and experimental of V2G Bidirectional control with MPC are composed of EV, PV Energy Resource, CSO with MPC, EVSE, Bidirectional, Metering, and software Protocol OCPP as shown in Fig.7 .

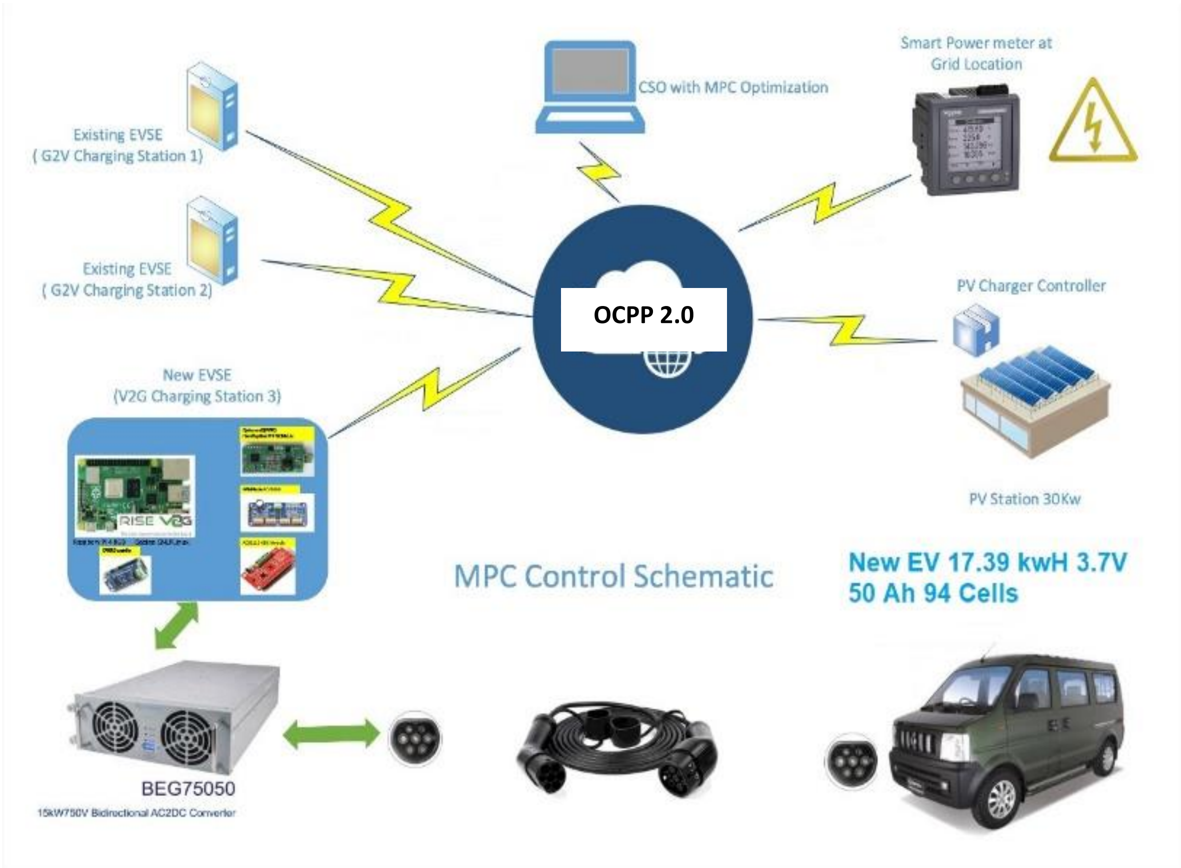

Fig.7 MPC V2G Control Strategy for Energy Trading Platform

The BEG75050 is a bidirectional electrical power variable device that connect to a three-phase alternating current power supply of 400 VAC and a DC 150VDC 750VDC battery with an electrical power of 15 KW. By varying the electrical power, it can be ordered to variable electrical power. Both directions are converted from AC to DC and vary from DC to AC as shown in Fig.8. The bidirectional power transfer capability of 30 kW EVSE Converter has been tested to verify the capability of G2V (Grid to Vehicle) Mode and V2G (Vehicle to Grid) Mode as shown in Fig. 9.

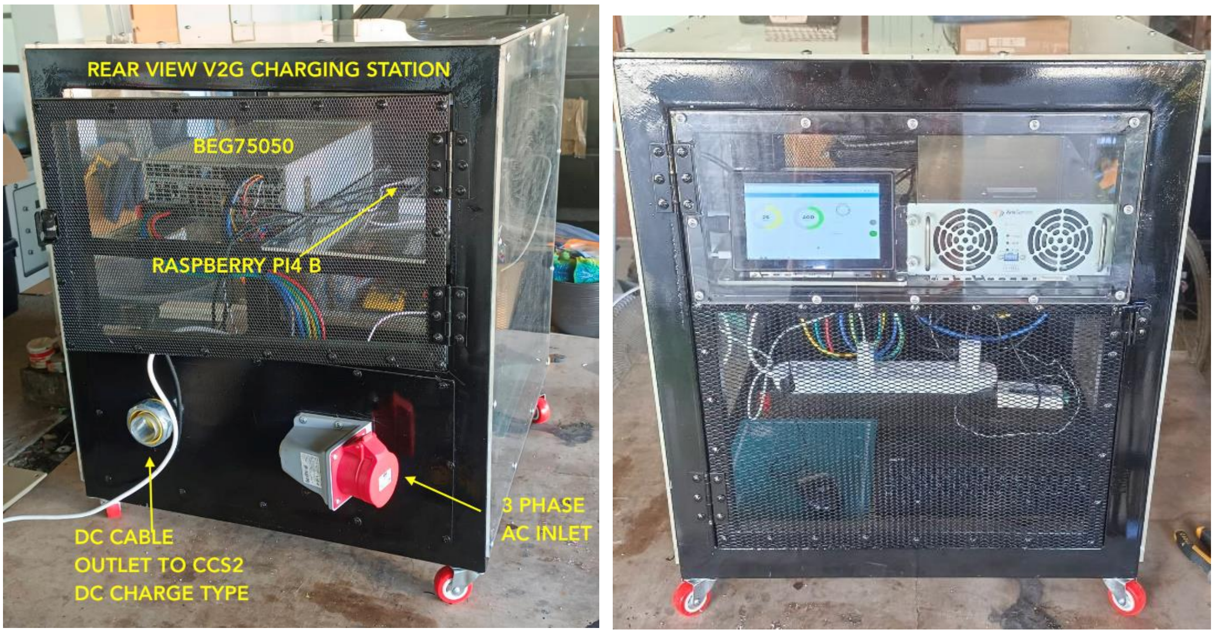

Fig 8 System Monitoring of V2G Bidirectional Charger

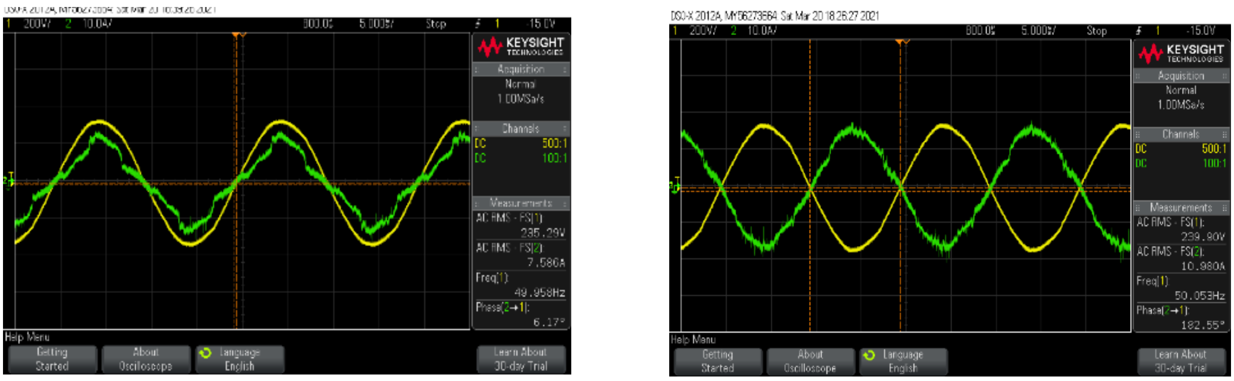

Fig 9 Experimental of Power Flow in Mode G2V and V2G

Design and development of a bi-directional automotive charging station management system on Platform Node Red, as shown in the flow of the V2G Server system as shown in Fig.10 and display the measuring parameter is shown in Fig.11.

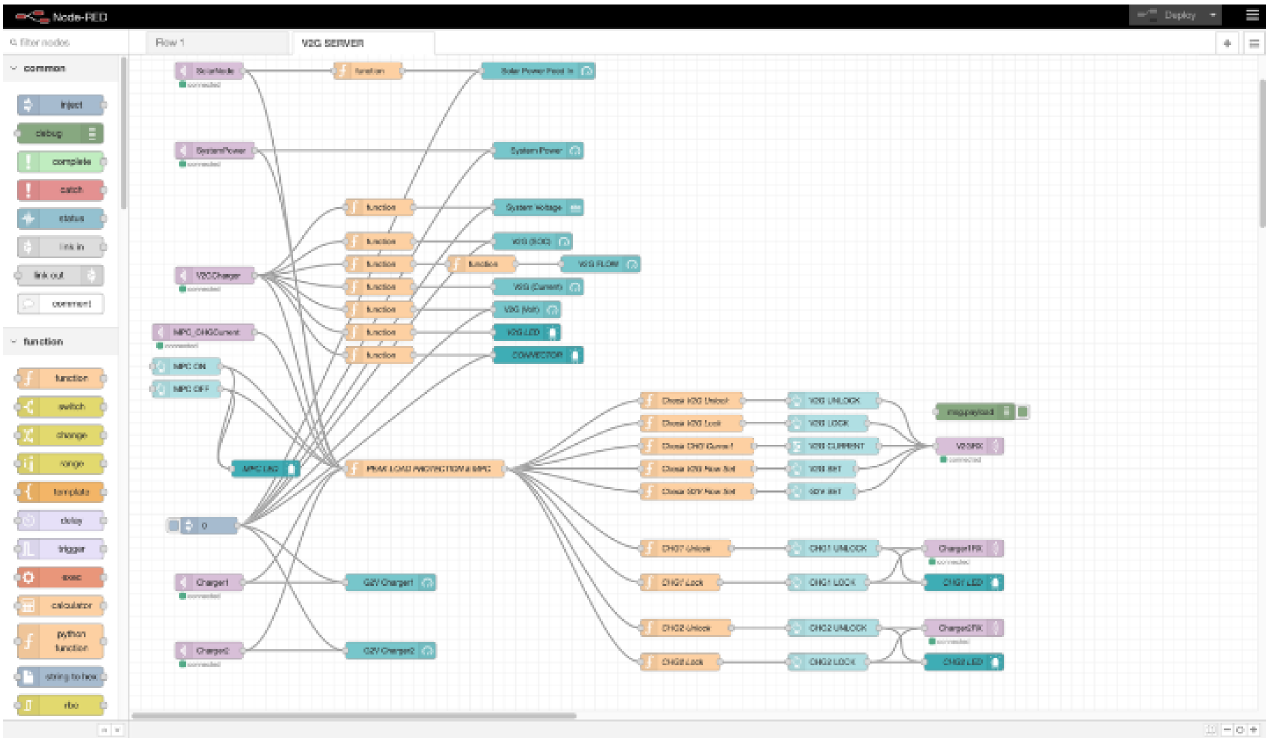

Fig.10 Diagram of NodeRED MCU of Charger monitoring and Control

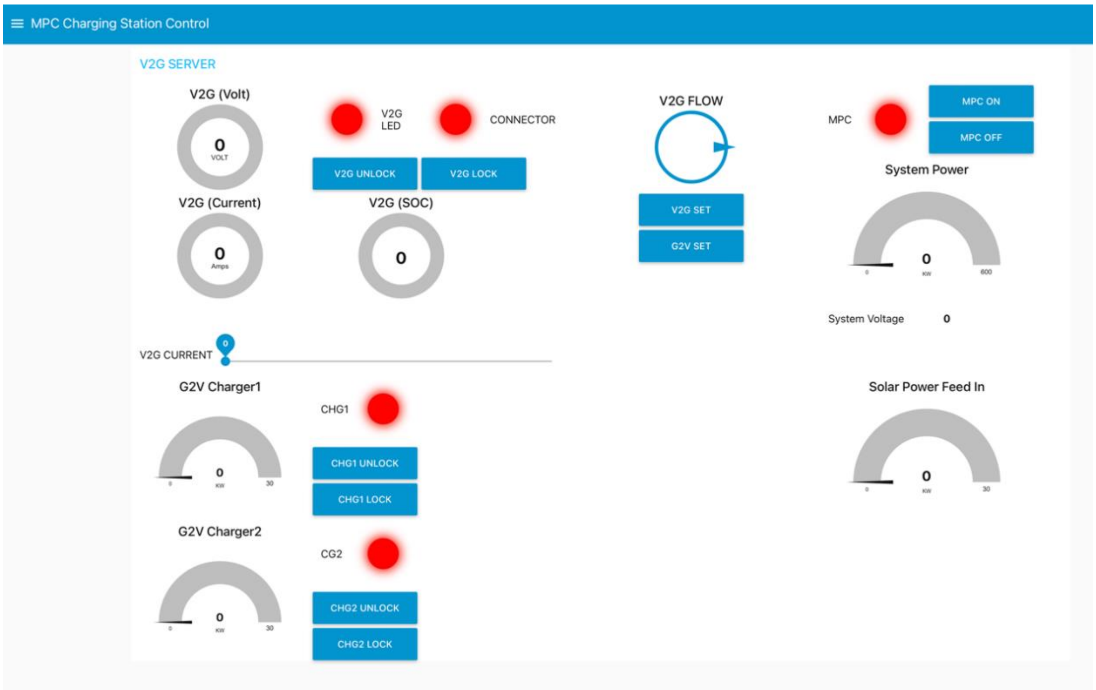

Fig.11 V2G Bidirectional Charger Dash Board

The Electricity Control Unit (VCU) will activate the DC magnetic contactor, connecting the DC CCS2 plug to the Battery Management System (BMS) that oversees the operation of an additional layer of batteries. The BMS is configured for fast charging, ensuring that the charging current does not exceed 50 A DC. The bi-directional charging station will display a green connector status indicator (L) once the vehicle is connected to the electric power supply. Additionally, the station will show the battery voltage and State of Charge (SOC) of the battery, which are calculated based on the variables transmitted from the VCU of the electric vehicle through an MQTT message identified as EVidentity. The battery voltage status, connector status, and SOC will all be displayed on the management system interface.

After connecting the electric vehicle charging station to the modified electric vehicle, testing can begin. The charging of electric power from the grid (G2V, or Grid to Vehicle) is controlled by setting the current value at CHG Current to 5 A, and the power flow mode is configured to G2V by pressing the G2V SET button. The arrow on the V2G FLOW icon will then point to the left. After that, press the V2G UNLOCK button to complete the command. From Fig.12, it can be observed that while charging the vehicle, the electric current is set at 5 A. The grid load distribution power increases from 350 kW to 351.76 kW, while the grid voltage decreases slightly from 412.59 VAC to 411.29 VAC. Additionally, the automotive battery voltage rises from 352.53 VDC to 353.74 VDC, and the State of Charge (SOC) increases from 62.96% to 64.64%.

Fig 12 Display of State of Charge Condition

After testing the G2V mode for charging, the electric vehicle returns to the V2G (Vehicle to Grid) mode. The current at CHG CURRENT is quickly set back to 5 A, as before. The V2G LOCK button is pressed to stop the charging of the electric vehicle at the charging station, which operates in both directions. The power flow mode is then set to V2G by pressing the V2G SET button, causing the arrow on the V2G FLOW icon to point to the right. After this, the V2G UNLOCK button is pressed to enable power transmission. At a current of 5 ADC, the grid load distribution power decreases from 350 KW to 348.23 kW. The grid voltage will increase slightly, from 412.59 to 413.72 VAC, the vehicle battery voltage will decrease. From 353.74 to 352.11 VDC and SOC also decreased from 64.64 to 62.38 as shown in Fig.13 - 14

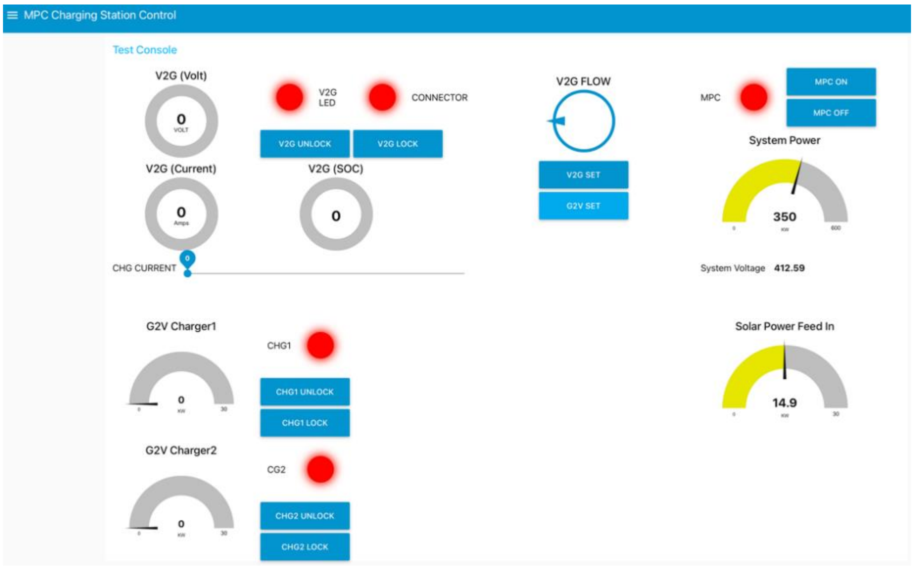

Fig.13 Monitoring System in V2G Bidirectional Mode

Fig.14 MPC Operation of EV Charger with Power Exceed Condition

The simulation results are displayed on the management system of the electric vehicle charging station, which operates in two directions. While the charging station is under the control of the management system, it is capable of charging two stations at 7 kW per station. However, this results in a maximum load that exceeds the grid's load limit. The simulation also includes two charging stations located outside of the system's control. When managing these stations at 7 kW each, combined with the current load of 396 kW (which is 98% of the maximum load), the total load reaches 406 kW. This causes the grid's protection system to activate, leading to trips or outages, resulting in a loss of electricity. If there are additional charging stations beyond the control of the bidirectional charging station management system, the load will increase further, potentially exceeding the maximum threshold. This situation could lead to significant damage to the system.

Conclusion

The development of a modified electric vehicle (EV) to support Vehicle-to-Grid (V2G) operation demonstrates that the vehicle can function as an energy storage system connected to a bidirectional charging station. The modified EV, equipped with a 17.79 kWh, 352.2 VDC battery, meets the requirements for V2G testing and operates effectively on roads, reaching a top speed of 120 km/h and handling hilly terrain thanks to the retention of its original manual transmission. The custom battery module performs efficiently, with an air-cooling system maintaining optimal temperatures during continuous use.

A 15 kW bidirectional power converter, controlled by Node-RED on a Raspberry Pi, manages charging and power discharge to the grid via CAN bus. The portable charging station, equipped with wheels, supports faster charging than the onboard charger, reducing charging time by fivefold. The bidirectional charging management system is developed using Node-RED on a MacBook Pro, communicating with the charging station through the MQTT protocol over the internet, enabling remote access without distance limitations. The optimal charging current is calculated in MATLAB, with parameter exchanges facilitated by offline MQTT between Node-RED and MATLAB on the same computer, allowing real-time predictive control due to high computing speeds.

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