A Review on GWO based Model Predictive Control in Vehicle-to-Grid

Rajesh Kumar [1], Dr. Abhimanyu kumar[2] and Chirag Gupta[3]
[1]*MTech Scholar,* [2]*AssistantProfessor* [3]*Associate professor*
[1]*Department of Electrical & Electronics Engineering, Vedica Institute of Technology, Bhopal, India*
[2]*Department of Electrical & Electronics Engineering, Vedica Institute of Technology, Bhopal, India*
[3]*Department of Electrical & Electronics Engineering, Vedica Institute of Technology, Bhopal, India*
[1]rk76031@gmail.co, [2]ies.abhi@gmail..com, [3]cgupta.011@gmail.com

Abstract- The power infrastructure is facing new difficulties as we move towards renewable energy sources that are variable, like wind and solar energy. Renewable energy production is extremely reliant on the weather, which limits its predictability and controllability and makes plants in general smaller and more dispersed. This work discusses the potential of integrating electric vehicles (EVs) with energy storage systems (ESS) to address the challenges of renewable energy integration and provide frequency support in microgrids. The high cost and degradation of ESS are limiting factors, and the collaboration with EVs offers a solution for stable microgrid operation.

Keywords: ***Power Infrastructure, Electric Vehicles (EVs), Energy Storage Systems (ESS).***

I. INTRODUCTION

Distribution System Operators (DSOs) play a pivotal role in ensuring the efficiency and reliability of medium and low voltage distribution grids. A key consideration for these operators arises from the increasing demand associated with electric vehicle (EV) charging. Such demand pushes the low voltage distribution grid towards its maximum capacity. To maintain the reliability of the grid, DSOs must prevent congestion, a situation where components like transformers or distribution lines approach or exceed their operational limits. Herein, we'll refer to these vulnerable areas as "congestion zones." In instances where a congestion zone becomes overwhelmed, safety mechanisms such as fuses intervene. While these fuses serve as crucial safety measures, they can potentially increase the pressure on local infrastructure components. To tackle these challenges, DSOs are looking towards congestion management using energy flexibility. Through strategic pricing structures and leveraging market dynamics, they aim to circumvent the onset of congestion. Aggregators that oversee power scheduling can factor in these congestion management guidelines, given their control over energy distribution across their networks[1]. It provides both a granular view of individual substations and a broader overview of the entire system. In this representation, EVs connect to specific branches of the detailed grid segment, all of which feed into the primary substation. Both the branches and the substations are potential congestion zones. For clarity, let's consider a substation that demonstrates critical flow in one of its branches, signaling a possible congestion threat. This micro-level view then ties into a macro-level perspective, depicting how each substation connects to a wider network. The connections between higher and lower voltage substations are also illustrated.

For an aggregator to effectively aid DSOs in congestion management, understanding the specific congestion zones connected to energy flexibility sources is crucial. They categorize these connections using subsets within their configurations. Each subset represents all the energy flexibility providers linked to a particular congestion zone. Notably, many literary sources on aggregator challenges overlook this geospatial data, often applying a singular network constraint. However, for an aggregator, this spatial detail is invaluable as it allows them to offer targeted congestion management services.

II. THE ELECTRIC VEHICLE AGGREGATOR

In the context of interest, an EV fleet is directly under the aggregator's control. The requirements that must be fulfilled for an EV are established by the owner, such as the intended departure time and the desired State of Charge (SoC).

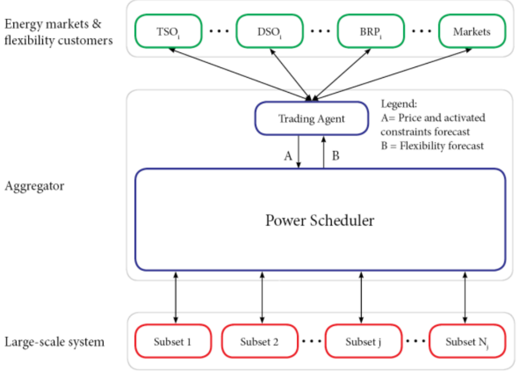

Fig 1: Schematic representation of the aggregator setting with respect to potential energy flexibility users and the EV fleet, which are divided over the subsets.

III. CENTRALIZED MODEL PREDICTIVE CONTROL

In the realm of electric vehicle (EV) coordination, the aggregator plays a pivotal role in overseeing the entire EV fleet. Such centralized oversight ensures improved energy distribution and more efficient demand-response choices. Yet, even with the aggregator overseeing charging, the vehicle's primary needs still reflect the owner's priorities. Key aspects that cannot be compromised include the scheduled departure time and the targeted State of Charge (SoC).

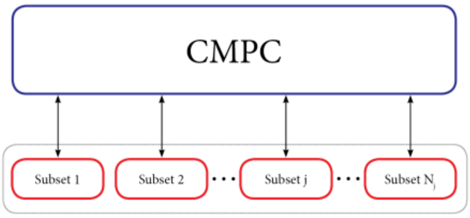

Fig 2: Communication structure of the CMPC algorithm

IV. DISTRIBUTED MODEL PREDICTIVE CONTROL USING RESOURCE ALLOCATION

To address the power scheduling issue outlined in Section 2-1, a Distributed Model Predictive Control with Resource Allocation (DMPC-RA) method is created. It is illustrated how the created DMPC-RA algorithm communicates in Fig. 3.

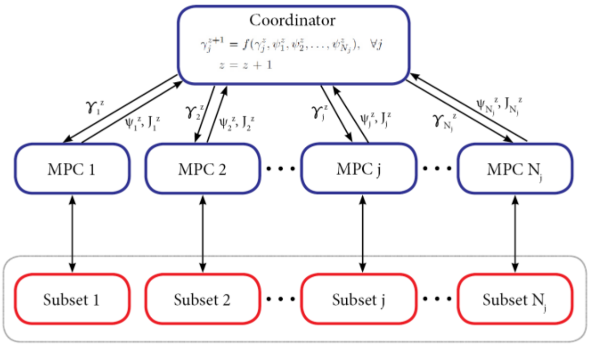

Fig 3: Communication structure of the developed DMPC-RA algorithm

V. LITERATURE REVIEW

Nguyen et al. [1] introduced a model for managing energy in smart electric vehicle charging stations that incorporate vehicle-to-grid (V2G) and vehicle-to-vehicle (V2V) capabilities. They used a penalty approach to enhance computational speed, making sure electric vehicles didn't charge and discharge at the same time.

Abdelghaffar et al. [2] detailed the use of model predictive control for onboard battery chargers in multi-phase EV drive trains. As phase numbers grow, the process becomes intricate, but it allows better control optimization. Adjusting the control for different fault instances is straightforward.

Chai et al. [3] developed a two-step method to decide how electric vehicles involved in a V2G program at an office should charge or discharge. The process optimizes electricity bills while considering the convenience of EV owners. An extensive cost-benefit analysis was also done.

Hou et al. [4] explored managing a solar-hydrogen microgrid with various components, including zero-emission vehicles. They proposed a two-phase stochastic optimization method to decide optimal power management strategies. This method was proven to reduce operating costs significantly.

Zhang et al. [5] presented an online system for combining ride-sharing with V2G scheduling. They addressed forecast uncertainties and demonstrated the model's effectiveness in improving citywide ride-sharing and V2G regulation while ensuring reduced operation costs.

Khan et al. [6] discussed strategies to harmonize EV chargers, energy storage systems, and smart charging methods in a vehicle-to-grid system. They introduced two charging strategies and showcased their efficiency through simulations.

Kumar et al. [7]–[9] introduced a control strategy to schedule energy in a community of prosumers with V1G and V2B capabilities. The model accounted for the unpredictable nature of electric vehicles' availability.

Gupta et al. [10]–[12] anticipated renewable energy generation and analyzed an EV parking station's operation that didn't rely on commercial power. They demonstrated the economic benefits of introducing demand response to EVs.

Authors in [6], [8], [13]–[15] introduced a solution for certain power management problems using BC-ST SMC. They demonstrated its advantages over other controllers, particularly in real-time control scenarios.

Few authors in [16]–[19] designed an adaptive cruise control system focusing on energy management and safety. Their innovative approach allowed for safer vehicle following and better energy management.

Masood et al. [20] described a system model using an adaptive sliding mode controller. They showcased various driving and parking mode functionalities and compared their model with other control methods.

Kumar et al. [21] introduced an optimized controller to reduce frequency and voltage fluctuations. The controller was paired with dynamic energy storage devices and showcased its superiority over existing methods.

Kannayeram et.al. [22] developed a hybrid system to evaluate the impact of EV charging stations paired with renewable sources. Their method aimed to enhance network power and reduce costs.

Itoo et al. [23] offered a new authentication protocol to ensure secure V2G communications. The protocol employed lightweight cryptographic methods to optimize resource use.

Jang et al. [24] employed data-driven techniques to assess V2G flexibility, using data from Korean charging stations. They provided a method to estimate the flexibility over time, considering various factors.

Jaworski et al. [25] introduced an efficient algorithm that yielded substantial charging cost savings. Their results emphasized the importance of using precise battery models.

Khan et al. [26] showcased power converter designs that demonstrate the potential of SiC and GaN semiconductors for enhanced power density and efficiency.

Li et al. [27] introduced a battery power capability estimation method to prevent batteries from reaching dangerous operating conditions. Their approach combined an electrochemical-thermal battery model with nonlinear model predictive control.

Rahman et al. [28] created a model to predict energy availability and cost for V2G applications across various temperatures. They identified key parameters influencing economic performance.

VI. CONCLUSION

This study delves into the challenge of maintaining frequency stability in isolated microgrids (MGs). We explore a range of control strategies such as proportional integral (PI), fuzzy logic proportional integral (FPI), and model predictive control (MPC). The system encompasses electric vehicles (EVs), an energy storage system (ESS), a wind turbine, solar panels, and a diesel generator. These controllers aim to modulate the energy output from the ESS and the EV batteries. Furthermore, we examine the influence of load fluctuations and heightened renewable energy integration on the system's frequency.

REFERENCES

[1] H. T. Nguyen and D.-H. Choi, “Distributionally Robust Model Predictive Control for Smart Electric Vehicle Charging Station with V2G/V2V Capability,” IEEE Trans. Smart Grid, p. 1, 2023, doi: 10.1109/TSG.2023.3263470.

[2] S. Abdelghaffar, A. Abdel-Khalik, and R. Hamdy, “Predictive Current Control Scheme for Post-Fault Operation of Nine-Phase-Based Integrated Onboard Chargers,” in 2023 XIX International Scientific Technical Conference Alternating Current Electric Drives (ACED), 2023, pp. 1–6. doi: 10.1109/ACED57798.2023.10143441.

[3] Y. T. Chai, H. S. Che, C. Tan, W.-N. Tan, S.-C. Yip, and M.-T. Gan, “A two-stage optimization method for Vehicle to Grid coordination considering building and Electric Vehicle user expectations,” Int. J. Electr. Power Energy Syst., vol. 148, p. 108984, 2023, doi: https://doi.org/10.1016/j.ijepes.2023.108984.

[4] L. Hou, J. Dong, O. E. Herrera, and W. Mérida, “Energy management for solar-hydrogen microgrids with vehicle-to-grid and power-to-gas transactions,” Int. J. Hydrogen Energy, vol. 48, no. 5, pp. 2013–2029, 2023, doi: https://doi.org/10.1016/j.ijhydene.2022.09.238.

[5] S. Zhang and J. J. Q. Yu, “Online Joint Ride-Sharing and Dynamic Vehicle-to-Grid Coordination for Connected Electric Vehicle System,” IEEE Trans. Transp. Electrif., p. 1, 2023, doi: 10.1109/TTE.2023.3284423.

[6] S. Khan, C. Gupta, and A. Kumar, “An Analysis of Electric Vehicles Charging Technology and Optimal Size Estimation,” vol. 04, no. 04, pp. 125–131, 2021.

[7] A. Kumar and S. Jain, “Enhancement of Power Quality with Increased Levels of Multi-level Inverters in Smart Grid Applications,” vol. 14, no. 4, pp. 1–5, 2022, doi: 10.18090/samriddhi.v14i04.07.

[8] A. Kumar and S. Jain, “A Review on Cascaded Multilevel Inverter with Different Levels,” pp. 134–137, 2019.

[9] A. Kumar and S. Jain, “Critical Analysis on Multilevel Inverter Designs for,” vol. 14, no. 3, 2022, doi: 10.18090/samriddhi.v14i03.22.

[10] C. Gupta and V. K. Aharwal, “Design and simulation of Multi-Input Converter for Renewable energy sources,” J. Integr. Sci. Technol., vol. 11, no. 3, pp. 1–7, 2023.

[11] C. Gupta and V. K. Aharwal, “Optimizing the performance of Triple Input DC-DC converter in an Integrated System,” J. Integr. Sci. Technol., vol. 10, no. 3, pp. 215–220, 2022.

[12] C. Gupta, V. K. Aharwal, and M. Pradesh, “Design of Multi Input Converter Topology for Distinct Energy Sources,” SAMRIDDHI, vol. 14, no. 4, pp. 1–5, 2022, doi: 10.18090/samriddhi.v14i04.09.

[13] B. B. Khatua, C. Gupta, and A. Kumar, “Harmonic Investigation Analysis of Cascade H Bridge Multilevel Inverter with Conventional Inverter using PSIM,” vol. 04, no. 03, pp. 9–14, 2021.

[14] A. Raj, A. Kumar, and C. Gupta, “Shunt Active Filters : A Review on Control Techniques II . Shunt Active Power Filter,” vol. 05, no. 02, pp. 78–81, 2022.

[15] S. Kumar and A. Kumar, “Single Phase Seventeen Level Fuzzy-PWM Based Multicarrier Multilevel Inverter with Reduced Number of Switches”.

[16] R. Kumar and C. Gupta, “Methods for Reducing Harmonics in Wind Energy Conversion Systems : A Review I . Introduction II . Wind Energy Conversion System III . Harmonic Mitigation Methods,” vol. 04, no. 02, pp. 1–5, 2021.

[17] P. Verma and C. Gupta, “A Survey on Grid Connected Solar Photovoltaic System,” Int. Conf. Contemp. Technol. Solut. Towar. fulfilment Soc. Needs, pp. 106–110, 2018, [Online]. Available: https://www.academia.edu/37819420/A_Survey_on_Grid_Connected_Solar_Photovoltaic_System

[18] K. Jagwani, “Contemporary Technological Solutions towards fulfilment of Social Needs A Design Analysis of Energy Saving Through Regenerative Braking in Diesel Locomotive with Super-capacitors,” pp. 94–99, 2018.

[19] V. Meena and C. Gupta, “A Review of Design , Development , Control and Applications of DC − DC Converters,” no. 2581, pp. 28–33, 2018.

[20] M. Mehrasa, H. Salehfar, D. F. Selvaraj, and S. I. Ahmed, “Smart bidirectional charging for frequency support of a low-inertia vehicle-to-grid system in presence of energy storage systems,” in 2023 IEEE Texas Power and Energy Conference (TPEC), 2023, pp. 1–6. doi: 10.1109/TPEC56611.2023.10078605.

[21] N. Mignoni, “Distributed Noncooperative MPC for Energy Scheduling of Charging and Trading Electric Vehicles in Energy Communities Distributed Noncooperative MPC for Energy Scheduling of Charging and Trading Electric Vehicles in Energy Communities,” 2023, doi: 10.36227/techrxiv.22785401.v1.

[22] S. Ueda et al., “Optimal Operation of Park and Ride EV Stations in Island Operation with Model Predictive Control,” pp. 1–17, 2023.

[23] A. Zar, I. Ahmad, M. S. Nazir, and I. Ahmed, “Fuzzy optimized conditioned-barrier nonlinear control of electric vehicle for grid to vehicle & vehicle to grid applications,” J. Energy Storage, vol. 64, p. 107251, 2023, doi: https://doi.org/10.1016/j.est.2023.107251.

[24] R. Zhang et al., “Constrained hybrid optimal model predictive control for intelligent electric vehicle adaptive cruise using energy storage management strategy,” J. Energy Storage, vol. 65, p. 107383, 2023, doi: https://doi.org/10.1016/j.est.2023.107383.

[25] U. Masood, M. K. Azeem, I. Ahmad, and A. ul Jabbar, “Robust adaptive nonlinear control of plugin hybrid electric vehicles for vehicle to grid and grid to vehicle power flow with hybrid energy storage system,” ISA Trans., 2023, doi: https://doi.org/10.1016/j.isatra.2023.03.035.

[26] V. Kumar, V. Sharma, and R. Naresh, “Model Predictive Controller-Based Voltage and Frequency Regulation in Renewable Energy Integrated Power System Coordinated

with Virtual Inertia and Redox Flow Battery," Iran. J. Sci. Technol. Trans. Electr. Eng., vol. 47, no. 1, pp. 159–176, 2023, doi: 10.1007/s40998-022-00561-x.

[27] G. Kannayeram, R. Muniraj, and R. Saravanan, "Impacts of electric vehicle charging station with the integration of renewable energy with grid connected system: a hybrid technique," Clean Technol. Environ. Policy, 2023, doi: 10.1007/s10098-023-02548-6.

[28] S. Itoo, L. K. Som, M. Ahmad, R. Baksh, and F. S. Masoodi, "A robust ECC-based authentication framework for energy internet (EI)-based vehicle to grid communication system," Veh. Commun., vol. 41, p. 100612, 2023, doi: https://doi.org/10.1016/j.vehcom.2023.100612.