International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 6, Nov-Dec 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Design and Control of a Transformerless MPPT-Based Bidirectional Buck–Boost Converter for Solar-Assisted Electric Vehicle Battery Charging

Vikesh Kumar Singh[1], Rajiv Thakur[2]

[1]M Tech Scholar, NRI Institute of Information Science and Technology, Bhopal, Madhya Pradesh, India
[2]Professor, NRI Institute of Information Science and Technology, Bhopal, Madhya Pradesh, India

ABSTRACT

Recent growth in electric vehicle (EV) deployment has intensified the need for sustainable and renewable-energy-based charging systems to reduce emissions and dependence on fossil fuels. This paper presents the design and control of a transformerless MPPT-based bidirectional buck–boost converter for a solar photovoltaic (PV) battery-powered electric vehicle. The proposed system enables efficient power transfer between the PV array, battery energy storage, and EV drive through bidirectional operation, allowing both battery charging and discharging. Maximum Power Point Tracking (MPPT) using the Perturb and Observe (P&O) algorithm is implemented to extract maximum power from the PV array under varying irradiance conditions. A closed-loop PI controller is employed to regulate the DC bus voltage at 90 V, ensuring stable EV operation. The proposed transformerless buck–boost topology reduces component count, conduction losses, and overall system cost while maintaining high conversion efficiency. The complete system is modeled and simulated in MATLAB/Simulink under irradiance variations of 1000–500–1000 W/m² at 25°C. Simulation results demonstrate effective MPPT operation, stable DC bus voltage regulation, smooth battery charging and discharging, and reliable PMDC motor performance, validating the suitability of the proposed architecture for solar-assisted electric vehicle applications.

KEYWORDS: *Electric Vehicle Charging; Solar PV Integration; MPPT (P&O); Transformerless Bidirectional Buck–Boost Converter; Battery Energy Storage; DC Bus Voltage Regulation.*

How to cite this paper: Vikesh Kumar Singh | Rajiv Thakur "Design and Control of a Transformerless MPPT-Based Bidirectional Buck–Boost Converter for Solar-Assisted Electric Vehicle Battery Charging" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-6, December 2025, pp.853-858, URL: www.ijtsrd.com/papers/ijtsrd99984.pdf

IJTSRD99984

1. INTRODUCTION

Air pollution has emerged as one of the most critical global challenges, with the transportation sector being a major contributor due to excessive fossil fuel consumption. Vehicular emissions containing particulate matter (PM), nitrogen oxides, and greenhouse gases have resulted in severe health and environmental impacts worldwide [1]. Rapid urbanization and motorization have further aggravated this issue, especially in developing countries such as India, where the vehicle population is increasing exponentially.

Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) have gained significant attention as promising alternatives to internal combustion engine vehicles due to their zero tailpipe emissions and high energy efficiency [2]. Governments across the world have introduced stringent emission regulations and financial incentives to promote EV adoption. However, large-scale EV penetration demands clean and reliable charging infrastructure to ensure true environmental sustainability.

Solar photovoltaic (PV)–based EV charging systems offer a viable solution by utilizing renewable energy directly for battery charging, thereby reducing grid dependency and associated emissions. Solar-assisted EVs provide additional advantages such as improved power quality, reduced transmission losses, direct DC coupling, and support for vehicle-to-grid (V2G) and vehicle-to-home (V2H) applications. Efficient integration of PV arrays, battery energy storage, and

EV drives requires advanced power electronic converters with effective control strategies [3].

Motivated by these requirements, this work proposes a transformerless MPPT-based bidirectional buck–boost converter for solar-assisted electric vehicle applications [4]. The key contributions of this paper include: (i) development of a transformerless bidirectional buck–boost converter with reduced component count and losses, (ii) implementation of P&O-based MPPT for efficient solar power extraction, (iii) closed-loop DC bus voltage regulation using a PI controller for stable EV operation, and (iv) comprehensive MATLAB/Simulink validation under varying solar irradiance conditions [5].

2. PHOTOVOLTAIC MODELLING

Photovoltaic (PV) arrays convert solar energy into electrical energy, where the output power depends on solar irradiance, temperature, and load conditions. Due to the nonlinear nature of PV characteristics, the operating point continuously varies with environmental changes [6]. Under uniform irradiance and temperature, the PV array exhibits a unique operating point known as the Maximum Power Point (MPP), at which maximum power is delivered to the load. To ensure efficient operation, Maximum Power Point Tracking (MPPT) algorithms are employed [7].

The PV array is modeled using the single-diode equivalent circuit, which provides a balance between modeling accuracy and computational simplicity. The output current of the PV array is expressed as:

$$I = I_{PV} - I_0 \left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_p}$$

where I_{PV} is the light-generated current, I_0 is the diode saturation current, R_s and R_p are the series and parallel resistances respectively, a is the diode ideality factor, and V_t is the thermal voltage.

The light-generated current varies with irradiance and temperature and is given by:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n}$$

The developed PV model accurately represents the nonlinear V–I and P–V characteristics and is suitable for dynamic simulations required for electric vehicle charging applications [8].

2.1. Stand -Alone Solar Power System

The stand-alone solar PV system consists of a PV array, a DC–DC boost converter, an MPPT controller, and a load. The PV array generates DC power based on irradiance and temperature conditions. Since the PV output voltage varies nonlinearly, a DC–DC boost converter is employed to perform impedance matching between the PV array and the DC bus [9]. By adjusting the duty cycle of the boost converter using an MPPT algorithm, the PV array is forced to operate at its maximum power point, ensuring efficient power transfer to the downstream converter stages.

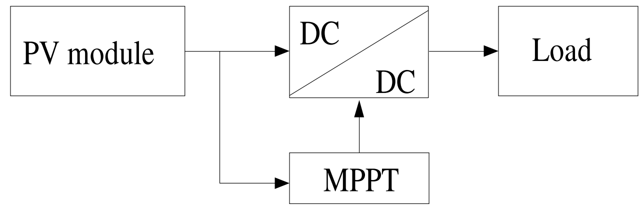

Fig. 1: Block Diagram of PV System with MPPT

2.2. Maximum Power Point Tracking

Maximum Power Point Tracking (MPPT) is essential to maximize energy extraction from PV arrays under varying environmental conditions. Among various MPPT techniques, the Perturb and Observe (P&O) algorithm is widely used due to its simplicity, robustness, and ease of implementation.

In the P&O method, the operating voltage of the PV array is perturbed slightly, and the resulting change in power is observed. If the power increases, the perturbation continues in the same direction; otherwise, it is reversed. This process allows the operating point to converge to the MPP [10].

The implemented P&O MPPT algorithm demonstrates rapid convergence to the MPP with minimal steady-state oscillations. Under sudden irradiance variations, the algorithm effectively tracks the new MPP, making it suitable for solar-assisted EV charging systems [11].

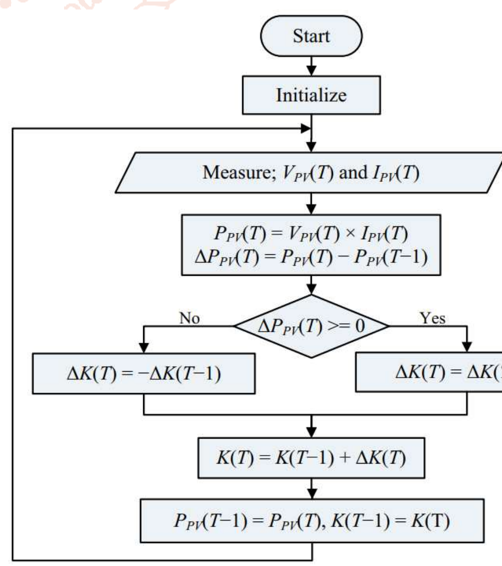

Fig. 2: Flowchart of P&O MPPT algorithm

3. TRANSFORMERLESS BUCK–BOOST CONVERTER

Transformerless DC–DC converters are preferred in electric vehicle applications due to their compact size, reduced losses, and high efficiency. The proposed transformerless buck–boost converter provides both step-up and step-down voltage conversion without galvanic isolation, enabling efficient integration of PV arrays, battery storage, and EV drives [12].

Unlike conventional buck–boost, SEPIC, or CUK converters, the proposed topology achieves higher voltage gain with fewer components and reduced voltage stress on switching devices. The absence of a transformer further minimizes losses and system cost, making it suitable for low-to-medium power EV applications.

3.1. System Design and Bidirectional Operation

The bidirectional DC–DC converter enables power flow between the PV array, battery, and DC bus in both directions. The converter operates in two distinct modes:

- **Mode-1 (Buck Mode – Battery Charging):**

When solar power exceeds load demand, the converter operates in buck mode to charge the battery. Switch S1 is turned ON while S2 remains OFF, allowing controlled energy transfer to the battery.

- **Mode-2 (Boost Mode – Battery Discharging):**

When solar power is insufficient, the converter operates in boost mode to supply power from the battery to the DC bus. Switch S2 is turned ON while S1 remains OFF.

Proper dead-time is incorporated between switching transitions to avoid shoot-through and cross-conduction. This bidirectional operation ensures uninterrupted power supply and efficient energy management.

4. PV ARRAY-BATTERY POWERED EV-PMDC DRIVE SCHEME

DC Motors have lots of desirable properties. Some of them are reliability, durable, inexpensive, and also using in low voltages, having positive conversion coefficients between electrical and mechanical, having size and design variation. For these reasons, the DC motors are utilized in many applications [13].

A permanent magnet dc motor (PMDC) is one of the DC motor types. PMDC system converts electrical power provided by a voltage source to mechanical power provided by a spinning rotor by means of magnetic coupling. The equivalent circuit of a PMDC motor is illustrated in Fig. 3. The armature coil of the dc motor can be presented by an inductance (L_m) in series with resistance (R_a) in series with an induced voltage (e_m) which opposes the voltage source [14 – 15].

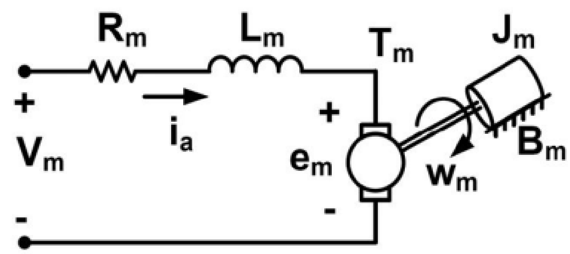

Fig. 3: The equivalent circuit of a dc motor

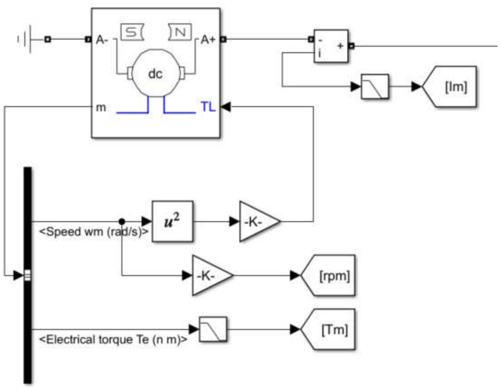

Fig. 4: The MATLAB/Simulink functional model of the PMDC motor

4.1. Simulation Results and Analysis

The complete EV model is simulated in MATLAB, the detailed simulation results along with discussions as follows.

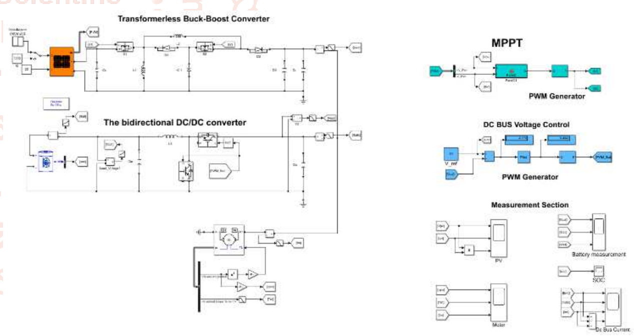

Fig. 5: Solar PV Battery Fed Electric Vehicle with Transformer less Buck Boost Converter

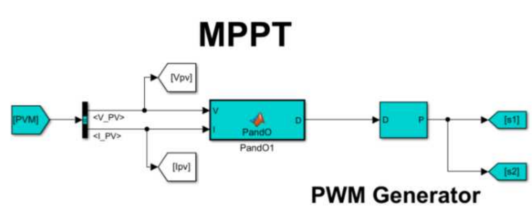

Fig. 6: MPPT Algorithm (P&O)

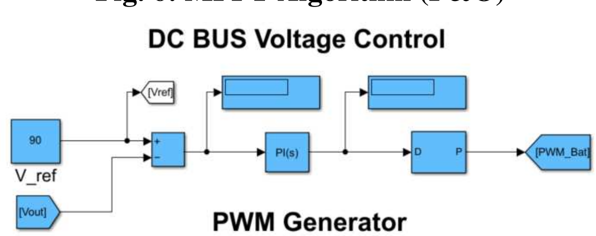

Fig. 7: DC Bus Voltage Control (PWM Generator)

To analyze the performance of the solar PV battery fed electric vehicle with transformer less buck boost converter. The PV parameters of the system are shown in Table I.

TABLE I: PV PARAMETERS

Parameters	Specifications
Maximum power (W)	**305.0063 W**
Parallel strings	**3**
Series-connected modules per string	**2**
Cells per module (Ncell)	**72**
Open circuit voltage Voc (V)	**44.88**
Short-circuit current Isc (A)	**8.95**
Voltage at maximum power point Vmp (V)	**35.59**
Current at maximum power point Imp (A)	**8.57**

At different irradiances (1000, 500, and 1000 IR) and temperatures of 25 degrees Celsius, the performance of a solar PV battery-fed electric vehicle with a transformer-less buck boost converter was evaluated. In solar mode, 1000 IR and 25 °C are utilized for 0-5 seconds of solar-powered electric vehicle operating, and the battery is charged with solar energy. In battery mode, 500 IR and 25 °C work in 5 to 10 seconds. Electric vehicle run entirely on battery power. Solar Mode was then cycled through for 10 to 15 seconds. SOC of battery is keep Increasing, motor speed, torque and current maintained.

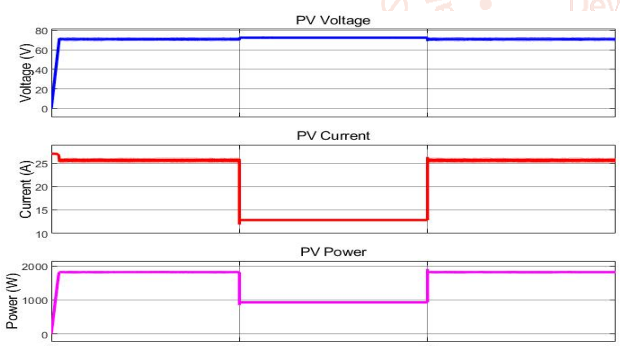

Fig. 8: PV Voltage, PV Current & PV Power Vs Time in (S)

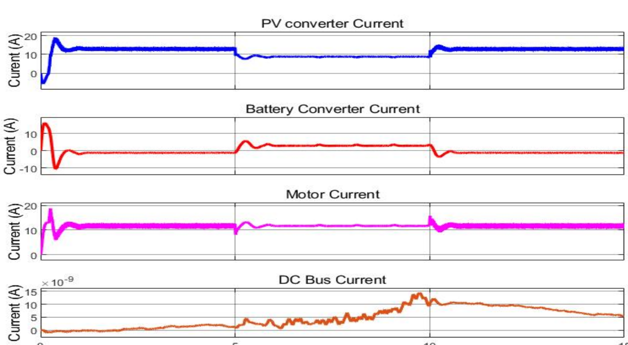

Fig. 9: PV Converter Current, Battery Converter Current, Motor Current & Dc Bus Current Vs Time in (S)

4 * 12V batteries with 48 Ah each are connected to a bidirectional DC/DC converter that is controlled by a DC bus voltage control system.

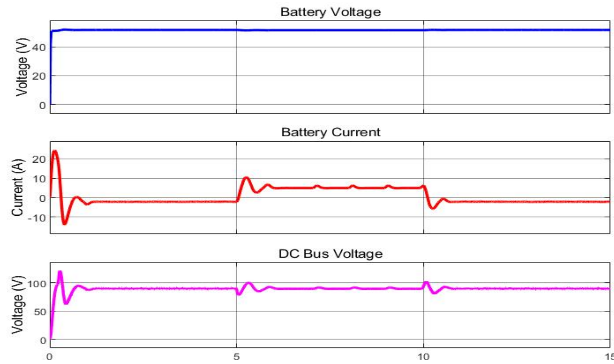

Fig. 10: Battery Voltage, Battery Current & Dc Bus Voltage Vs Time in (S)

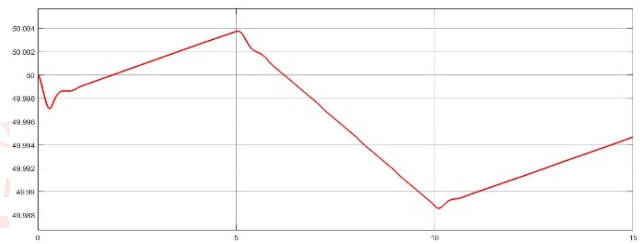

Fig. 11: State of charge - SOC % Vs Time in (S)

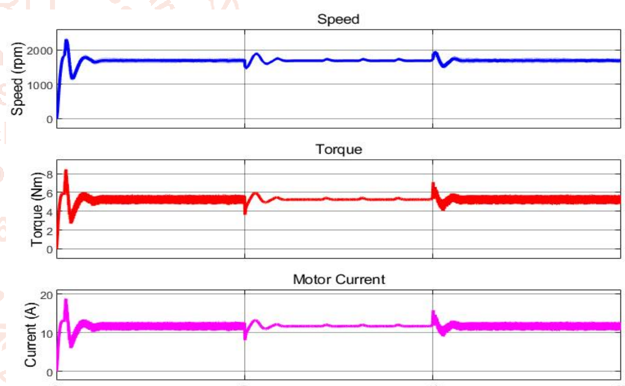

Fig. 12: Motor Speed, Motor Torque & Motor Current Vs Time in (S)

5. CONCLUSION

This research presents and evaluates a solar photovoltaic battery-powered electric vehicle using a transformerless buck-boost converter for optimal power point tracking. A transformerless buck-boost converter may function in both buck and boost modes, contingent upon the output requirements. A buck-boost converter is often used between the solar panel and the DC bus on the load side. The MPPT algorithm regulates the transformerless buck-boost converter (P&O). We provide the photovoltaic voltage and current to the Perturb and Observe Maximum Power Point Tracking, which produces the duty cycle. The pulse will be produced after the PWM generator has completed processing the duty cycle. Upon the application of that pulse to the Buck-Boost converter, it will optimize the extraction of maximum power from the photovoltaic panel. The PMDC motor will function as an electric car, drawing power from both solar and battery sources based on irradiance and temperature conditions. A bidirectional DC/DC converter, controlled by a DC bus voltage control system, is connected to the battery. Given that the PMDC motor rating is 90V, it is essential to sustain the DC bus voltage at 90V to operate the EV system. The PI controller will execute this procedure by generating the duty cycle for the PWM generator, which will then provide pulses for the bidirectional converter to regulate current flow and maintain voltage across the DC bus. The experimental results indicate that the topology may effectively enhance the energy transfer efficiency of MPPT technology, aligning with the future advancement of EV systems.

References

[1] Ijaz Ahmed; Muhammad Rehan; Abdul Basit; Muhammad Tufail; Keum-Shik Hong "A Dynamic Optimal Scheduling Strategy for Multi-Charging Scenarios of Plug-in-Electric Vehicles Over a Smart Grid" 2023 IEEE Access (Volume: 11).

[2] Alexander Balakhontsev; Oleksandr Beshta; Valery Boroday; Serhii Khudolii; Stanislav Pirienko "A Review of Topologies of Quick Charging Stations for Electric Vehicles" 2021 IEEE International Conference on Modern Electrical and Energy Systems (MEES).

[3] P. Srinivasa Rao Nayak; K. Kamalapathi; N. Laxman; Vipul Kumar Tyagi "Design and Simulation Of BUCK-BOOST Type Dual Input DC-DC Converter for Battery Charging Application in Electric Vehicle" 2021 International Conference on Sustainable Energy and Future Electric Transportation (SEFET).

[4] K. Vijayakumar "Solar Charging Infrastructure for E-vehicles - A Review" 2021 International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE).

[5] Renzun Zhang; Zening Li; Cunhao Wei; Yujing Li; Jin Yang; Su Su "Optimization and Solution Method for Electric Vehicle Charging and Discharging Load" 2021 IEEE 4th International Electrical and Energy Conference (CIEEC).

[6] Hilmi Cihan Güldorum; İbrahim Şengör; Ozan Erdinç "Charging Management System for Electric Vehicles considering Vehicle-to-Vehicle (V2V) Concept" 2020 12th International Conference on Electrical and Electronics Engineering (ELECO).

[7] Chang Liu; Jin Wang; Jiangpei Xu; Xiao Yu; Li Tian; Jie Wang; Liang Zhou; Deng Zhang "Key Security Challenges for Electric Vehicle Charging System" 2020 2nd International Conference on Artificial Intelligence and Advanced Manufacture (AIAM).

[8] Yun Zhang; Zhongwei Chen; Peizhe Li; Haotian Liu; Zhicheng Zhou; Leng Yang "Radiation Influence Model of Electric Vehicle Charging Station" 2020 IEEE 4th Conference on Energy Internet and Energy System Integration (EI2).

[9] B Preetha Yesheswini; S Jai Iswarya; Bontha Amani; Punnya Prakash; M R Sindhu "Solar PV Charging Station for Electric Vehicles" 2020 International Conference for Emerging Technology (INCET).

[10] Tamara Ninković; Martin Ćalasan; Saša Mujović "Coordination of electric vehicles charging in the distribution system" 2020 19th International Symposium INFOTEH-JAHORINA (INFOTEH).

[11] Fatemeh Jozi; Kazem Mazlumi; Hadi Hosseini "Charging and discharging coordination of electric vehicles in a parking lot considering the limitation of power exchange with the distribution system" 2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI).

[12] Egor Kulik; Xuan Trung Tran; Alecksey Anuchin; Yuriy Vagapov "GPS-track data processing for the optimization of the powertrain for hybrid electric vehicles" 2017 IEEE 58th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON).

[13] Somayyeh Khatiri-Doost; Meysam Amirahmadi "Peak shaving and power losses minimization by coordination of plug-in electric vehicles charging and discharging in smart grids" 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe).

[14] X. D. Xue; K. W. E. Cheng; S Raghu Raman; Jones Chan; J. Mei; C. D. Xu "Performance prediction of light electric vehicles powered by body-integrated super-capacitors" 2016 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and

Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC).

[15] Muhammad Sifatul Alam Chowdhury; Khandakar Abdulla Al Mamun; Al Mahmudur Rahman" Modelling and simulation of power system of battery, solar and fuel cell powered Hybrid Electric vehicle" 2016 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT).

[16] Viral Patel, Manish Chaturvedi, Sanjay Srivastava, Comparison of SUMO and SiMTraM for Indian Traffic Scenario Representation, Transportation Research Procedia, Volume 17, 2016, Pages 400-407, ISSN 2352-1465, https://doi.org/10.1016/j.trpro.2016.11.081.

[17] Pradeep Kumar Dongre, Viral Patel, Upendra Bhoi, Nilesh N. Maltare, An outlier detection framework for Air Quality Index prediction using linear and ensemble models, Decision Analytics Journal, Volume 14, 2025, 100546, ISSN 2772-6622, https://doi.org/10.1016/j.dajour.2025.100546.

[18] Viral Patel and Nilesh Maltare, From Algorithms to Connectivity: A Comprehensive Review of Traffic Signal Optimization and Communication Based Cooperative Control, Archives of Computational Methods in Engineering, Volume 32, 2025, ISSN: 1134-3060, https://doi.org/10.1007/s11831-025-10455-w