Solar-powered bidirectional charging of electric vehicle

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ABSTRACT

Solar-powered bidirectional charging of an electric vehicle has three different modes of operation. The first mode of operation is "solar-powered electric vehicle charging" in which the vehicle is charged with solar energy. The second mode of operation is "grid-powered electric vehicle charging" which charges the vehicle in the absence of solar energy. The third mode of operation is "vehicle supplying to the grid" and in this mode, the vehicle energy is transferred back to the grid when there is demand to charge the other electric vehicles connected to the same grid. The system uses maximum power point tracking (MPPT) to improve power extraction from solar panels under standard test cell conditions, allowing for effective charging of electric cars. It also uses a proportional-integral (PI) controller to continually monitor the battery's state of charge (SOC). This controller modulates the duty cycle of pulse width modulation (PWM), which regulates the charging current. The charging system includes a buck-boost converter, which functions as a buck converter while supplying grid voltage to the vehicle, and a boost converter in supplying excess voltage of the vehicle to the grid. For three different modes of operation, the battery parameters such as voltage, current, and charging state are presented. The grid voltage and current are observed for the last two modes of operation.

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1. INTRODUCTION

The transportation and energy industries are on the verge of a massive shift, fueled by a breakthrough technology: solar-powered bidirectional charging for electric vehicles. The use of solar electricity in bidirectional charging systems for electric vehicles (EVs) represents a significant step forward in sustainable and efficient transportation solutions [1]. This method not only meets the rising demand for renewable energy but also improves the overall resilience and stability of the electric grid [2]. Solar-powered bidirectional charging allows EVs to charge from and discharge energy back to the grid, resulting in a dynamic energy exchange system [3]. This bidirectional property is especially relevant in the context of renewable energy integration since it enables EVs to function as mobile energy storage units, hence improving grid stability and reducing reliance on non-renewable energy sources [4]. Advancements in photovoltaic technology, energy storage systems, and smart grid infrastructure have helped to accelerate the synergy between solar power and bidirectional charging [5]-[7]. This detailed analysis digs into the fundamental components of solar-powered bidirectional charging for EVs, looking at the technological, economic, and environmental implications of this novel paradigm [8]-[10].

Furthermore, the review looks at communication and control options for integrating EVs into the smart grid [11]-[13]. It assesses the problems and possibilities presented by vehicle-to-grid (V2G) technology, focusing on the potential for grid services and renewable energy integration [14]-[16]. It also investigates the legislative situation for solar electricity in India and worldwide advances in bidirectional wireless charging technologies [17], [18]. In summary, investigating the appropriate size, energy management, and design aspects of solar-assisted EV charging stations is critical to understanding the multifarious nature of this rapidly expanding sector [19]-[21]. This paper seeks to offer a full grasp of the solar-powered bidirectional charging scenario for electric vehicles by combining these many features.

Figure 1 depicts a block diagram of solar-powered bidirectional charging for an electric automobile. During the day, electric vehicles are powered by solar energy [22]-[24]. When solar power is lacking, the grid supplies electricity. An MPPT controller optimizes solar panel output. A boost converter boosts the solar panel power to 400 V for the DC connection, whereas a buck-boost converter charges the battery at 200 V. G2V mode converts grid AC power to DC for the DC connection, whereas V2G mode provides DC voltage from the battery [25]-[27].

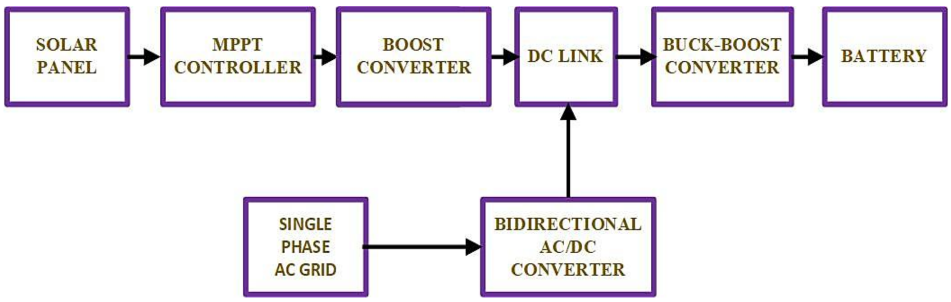

Figure 1. Block diagram of solar-powered bidirectional charging for an electric automobile

2. METHOD

This system, based on solar panels, electric vehicles (EVs), and the electrical grid, allows for a three-way flow of energy. It involves three different modes of operation: i) solar-powered electric vehicle charging, ii) grid-powered electric vehicle charging, and iii) electric vehicle supplying to the grid. The proper arrangement of passive filters in the circuit is critical for reaching peak performance in an electric vehicle (EV). This research [28]-[30] describes in full the design of passive components particular to the EV under evaluation.

The process begins with solar panels that convert sunlight into direct current (DC) power. Maximum power point tracking (MPPT) controller constantly adjusts the electrical operating point to maximize power generation while accounting for factors such as sunlight intensity and temperature [31]. The booster converter follows, increasing the DC voltage from the solar panels for more efficient power transfer and lower transmission losses. A DC link serves as an interface, connecting the booster converter to the buck-boost converter, which changes the voltage as required [32]. This enables compatibility with the electric vehicle's battery, which stores the energy generated by the solar panels. The bidirectional nature of the mechanism is critical. During charging, electricity is transferred from the solar panels to the electric vehicle battery via the converters. During draining, the battery can, on the other hand, feed any excess energy back into the grid. The buck-boost converter is critical in adjusting voltage levels to meet changing requirements or grid interactions [33]. The electric vehicle's battery functions as an energy reservoir, storing the power generated by the solar panels. When a vehicle is powered by the grid, a bidirectional AC/DC converter converts DC to AC power and AC to DC power. This component provides the flexibility necessary for dynamic energy management [34]. Finally, the system connects to a single-phase AC grid, which serves as an external power source. This grid offers additional electricity for charging the EV battery and takes in surplus energy when power is sent back into the system.

3. RESULTS AND DISCUSSION

3.1. Solar-powered electric vehicle charging

Figure 2 depicts the boost converter's switching pulses. These pulses govern when the converter turns on and off, regulating voltage and allowing for efficient energy transmission from the solar panels. From

Figure 3, it is clear that only the buck converter is turned on. Figure 4 depicts the solar PV array with MPPT voltage tracking. It has been discovered that solar panels may produce a maximum voltage of 200 volts in less than 0.2 seconds. Figure 5 depicts the boost converter's DC output voltage. The voltage is increased to 400 volts. This voltage is what allows for quick charging. Figure 6 depicts the battery's voltage and current. The voltage across the battery is around 210 V, with a current flow of 15 A. Figure 7 depicts the battery's state of charge (SOC) as it is charging. The battery charges from 98.999% to 99% in less than one second.

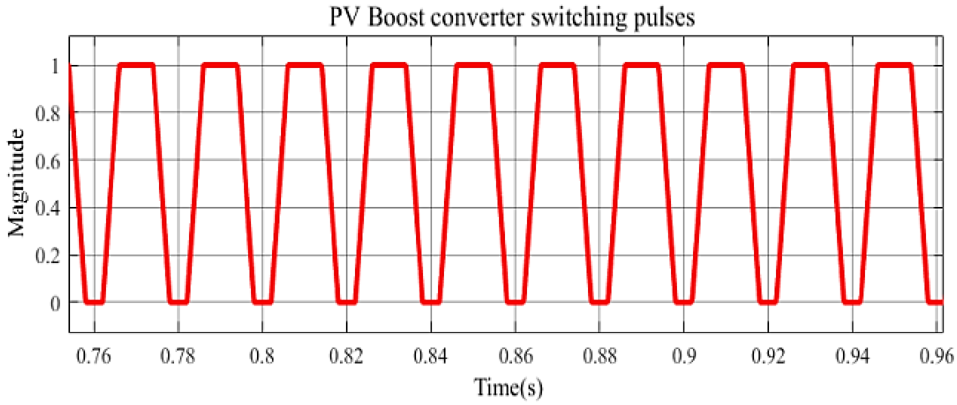

Figure 2. PV boost converter switching pulses

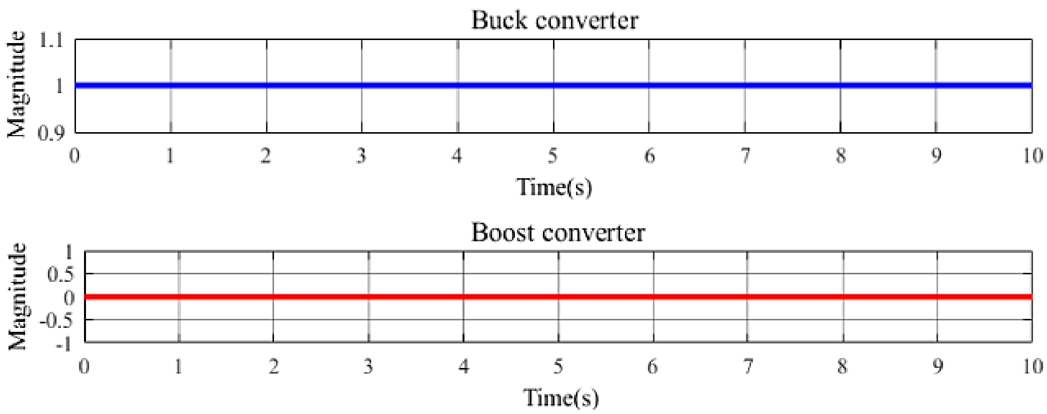

Figure 3. Buck-boost converter switching pulses

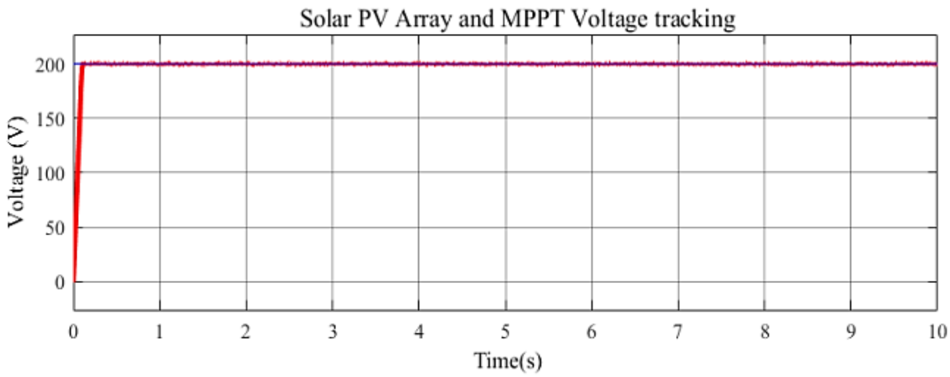

Figure 4. Solar PV array and MPPT voltage tracking

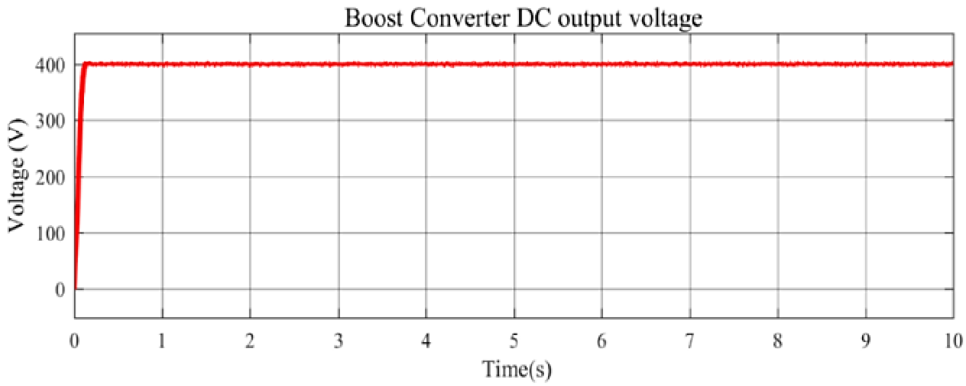

Figure 5. Boost converter DC output voltage

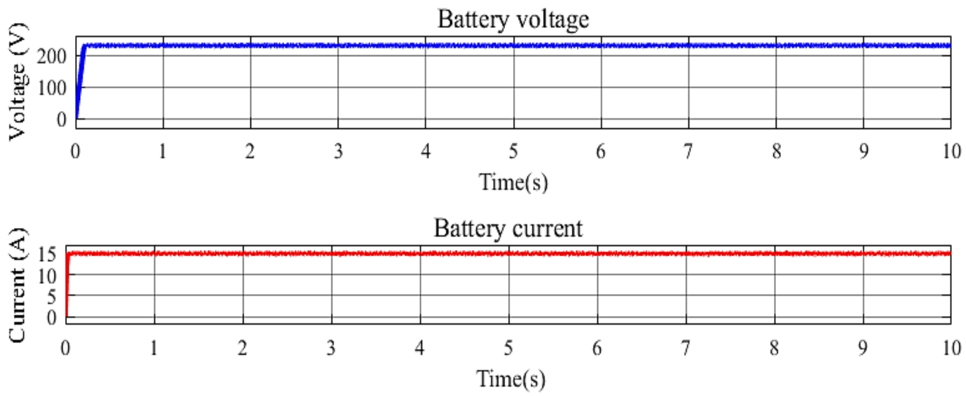

Figure 6. Battery voltage and current

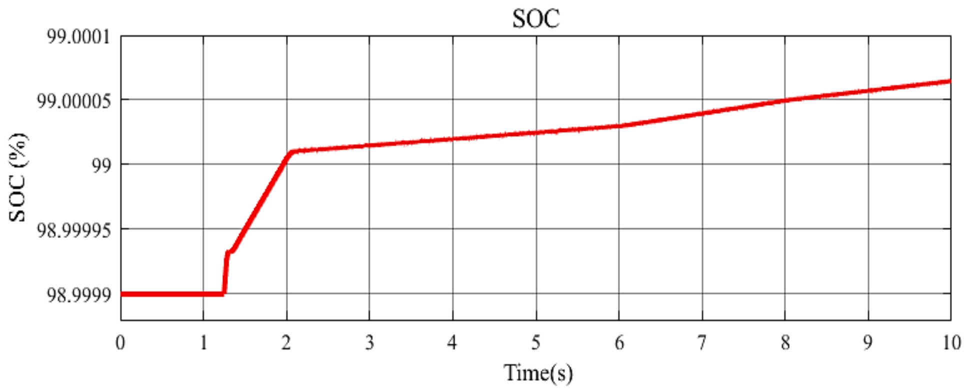

Figure 7. State of charge

3.2. Grid-powered electric vehicle charging

Figure 8 depicts the bidirectional converter's switching pulses. These pulses are required to convert the grid's alternating current (AC) electricity into direct current (DC) power for battery charging. Figure 9 depicts the waveforms of grid voltage and current. During the charging operation, the grid voltage remains in phase with the grid current. Figure 10 depicts the battery's voltage and current. The battery voltage is around 210 V, with a charging current of 10 A. Figure 11 depicts the battery's state of charge while it is in charging mode. The battery goes from 99.99% to 100% in 0.2 seconds.

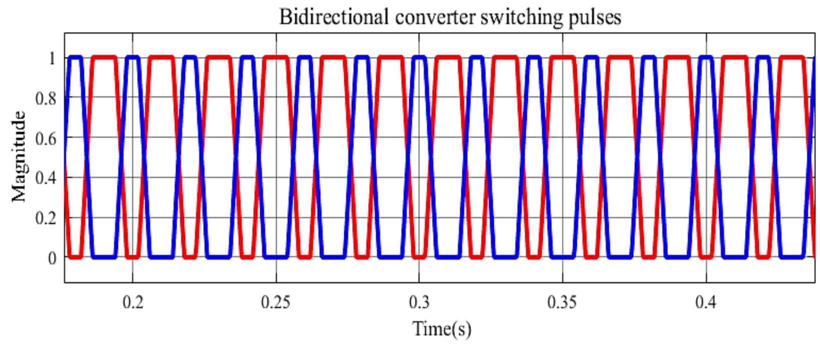

Figure 8. Bidirectional converter switching pulses

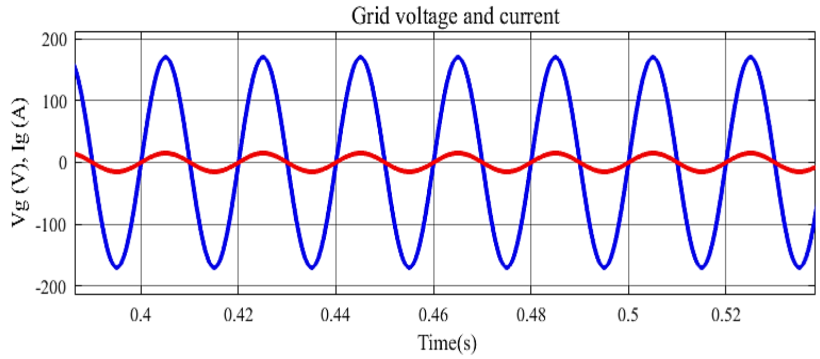

Figure 9. Grid voltage and current

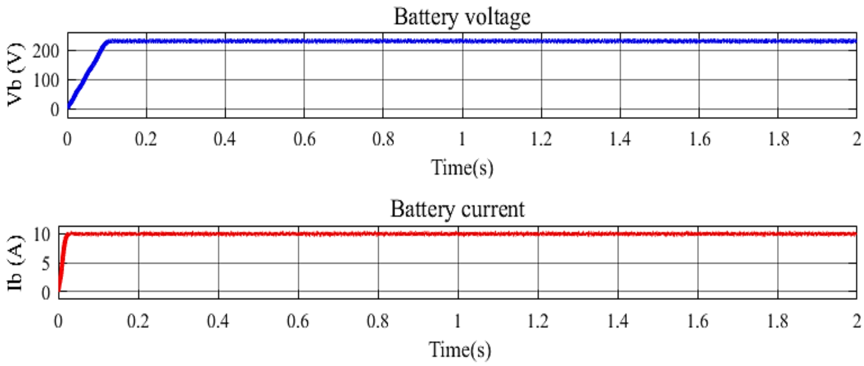

Figure 10. Battery voltage and current

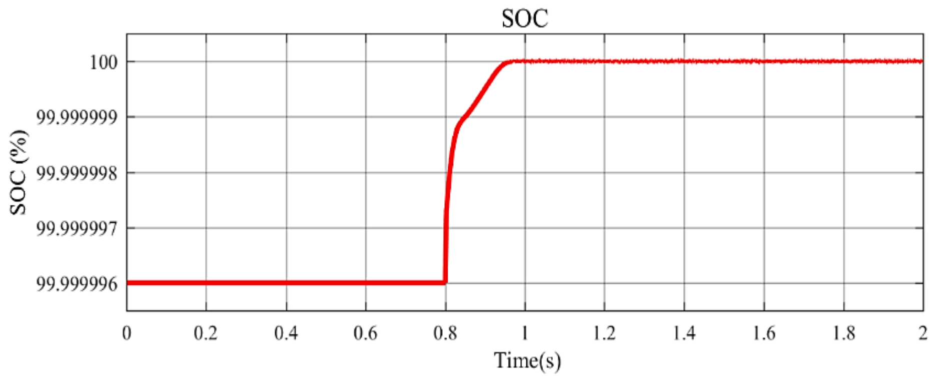

Figure 11. State of charge

3.3. Electric vehicle supplying to the grid

Figure 12 depicts the grid's voltage and current. The grid current is 180 degrees out of phase with the grid voltage, requiring an inverter operation to convert the DC power of the EV battery into AC power for the grid. Figure 13 depicts the battery's voltage and current. The battery voltage is found to fall from 400 V to -200 V. The battery current is seen to be negative, with a maximum value of -10 A. The negative readings indicate that the battery is draining. Figure 14 depicts the battery in the process of charging and discharging. It was noticed that the battery began to deplete after 0.75 seconds. The variation in parameters for three different modes of operation is described in Table 1.

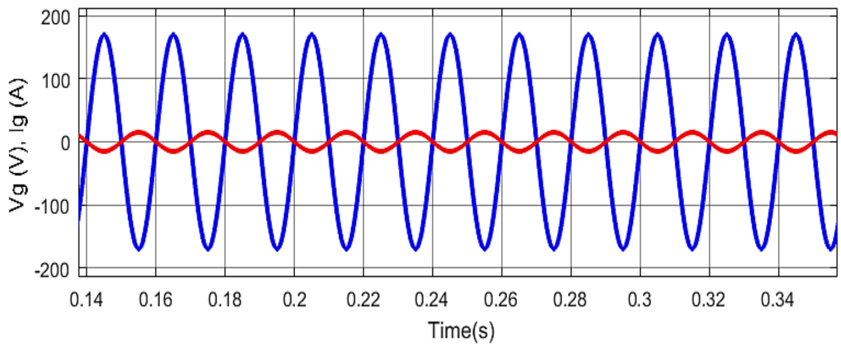

Figure 12. Grid voltage and current

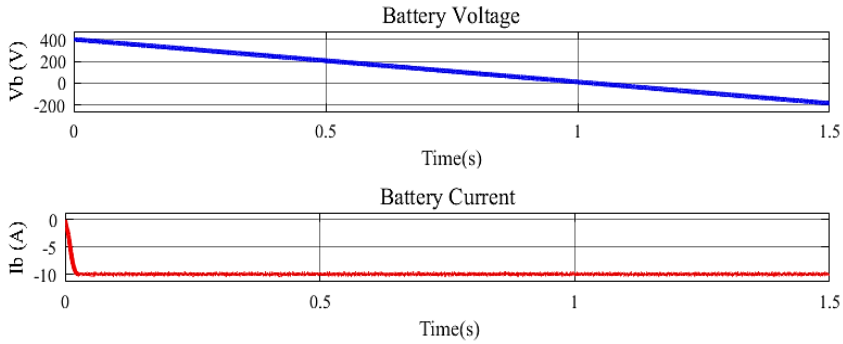

Figure 13. Battery voltage and current

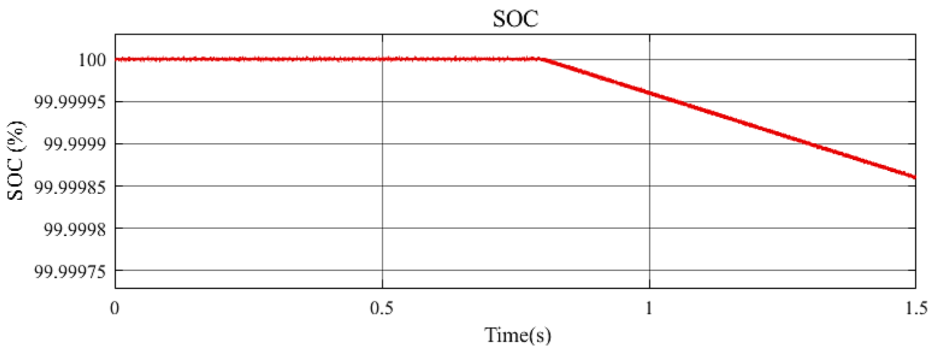

Figure 14. State of charge

Table 1. Variation in parameters for three different modes of operation

Mode	Grid voltage (V)	Grid current (A)	Battery voltage (V)	Battery current (A)	Battery SOC condition
A	0	0	200	15	Charging
B	175	10	200	10	Charging
C	175	-10	-200	-10	Discharging

4. CONCLUSION

The solar-powered bidirectional charging system for electric vehicles is a ground-breaking solution at the confluence of sustainable mobility and energy efficiency. The system provides dynamic energy exchange, allowing electric cars to charge from the grid in the absence of solar energy while returning extra energy during high-demand periods. The use of maximum power point tracking (MPPT) controllers results in effective power extraction from solar panels, which improves the overall efficiency of electric car charging. The bidirectional AC/DC converter and the buck-boost converter are crucial for reacting to different modes and offering flexibility in energy flow management. This revolutionary solution not only improves the sustainability of electric vehicle charging but also adds to grid stability, making a big step toward reducing reliance on nonrenewable energy sources. The Simulink model emphasizes the intricate interconnections between components, demonstrating the system's adaptability and efficiency and indicating a transformational influence on the future of electric vehicle charging and renewable energy integration.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Ravi Kumar Kallakunta		✓				✓		✓	✓	✓	✓	✓		
Sreevardhan Cheerla	✓		✓	✓			✓			✓	✓		✓	✓
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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