

## Performance analysis of a Novel Vehicle-To-Grid Technology Architecture in Power Systems

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| KEY WORDS                                                                                                                | ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
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| Electric Vehicles (EVs)<br>Bi-directional Power Converter<br>Fuzzy Logic Controller<br>Harmonic Distortion<br>Smart Grid | An efficient scheme for the management of energy storage for the grid can be greatly aided by electric vehicles (EVs). This process is managed by equipment that can store energy that connects vehicles to the grid (V2G). EVs contain batteries which can be used by the grid during transportation as potential energy storage devices. By storing surplus energy and subsequently resupplying it to the grid (V2G), EVs can aid in the management of the grid's energy. A downside to this strategy is that the battery in an electric vehicle degrades over time due to usage, thereby resulting in reduced performance. Improving battery lifetime requires stable power flow to be maintained during the V2G and G2V switching. This paper presents a novel architecture that leverages DC rapid charging and a combined d-q and fuzzy logic controller to construct a G2V and V2G concept for maintaining power stability. The proposed G2V and V2G model is simulated in Simulink and tested in normal operation, under battery cell temperature and load conditions. It was found that the bidirectional converter with fuzzy logic (FL) controller maintains the EV batteries during charging and discharging, whereas the d-q controller maintains the grid power. As evaluation, the outputs of the different units of the proposed system were verified for operation and the Total harmonic distortion (THD) of the proposed system was compared with previous work. The results indicate that at SOC state and variable cell temperature, the batteries equipped with the designed controller continue to supply stable power to the grid station. The harmonic distortion was found to be 2.41% and 2.08% with reliable operation under load. |

### 1. Introduction

The global energy landscape is at a crossroads, defined by the urgent, interlinked challenges of climate change, urban air quality, and geopolitical energy insecurity. Key to these problems is the transportation and power generation sector which contributes a significant portion of greenhouse gas emissions. The search for resilient, clean energy technologies has therefore been of increasing focus of researchers around the world [1].

Citing this phenomenon, the electrification of transportation has become a key step in this transition. Electric Vehicles (EVs) are considered not merely the replacement of the internal combustion engine, but as a keystone to the smart grid of the future. EVs provide

an immediate solution to the reduction of emissions and fossil fuel reliance by moving petroleum-powered vehicles to electricity. Moreover, due to the economics, they are fast gaining market penetration, especially in the urban areas [2]. A further advantage of this trend is that, alongside their use as efficient vehicles, their batteries can be used as a distributed network of energy storage assets at scale. This dual functional role is at the core of the Vehicle-to-Grid (V2G) paradigm.

The V2G concept, where EVs can bidirectionally allow energy flow between the power grid and the vehicle, has been of interest to researchers due to its potential for grid stability and possible integration of renewable energy. Its usefulness in the essential grid

services, like peak shaving, valley filling, and frequency regulation, has been confirmed by multiple researchers [3]. Studies have worked on advanced control schemes, such as AI-based management of hybrid renewable stations [4] and optimization algorithms for regulating grid demands and driver constraints [5, 6]. While there have been several approaches to various aspects of this task, such as AC charging and responsive bi-directional flow. An important consideration is the issue of power quality and harmonic distortion that is caused by the frequent switching of power electronic interfaces, resulting in charge and discharge cycles. To grid operators, this represents a major barrier to practical implementation since the stability of power is paramount to ensure the safety and reliability of systems.

The current work aims to address these gaps by shifting the emphasis from a fleet-level algorithm to the control architecture and the physical aspect of the charging point. A novel model of a grid-tied, DC fast-charging station utilizing a d-q controller and fuzzy logic controller combination that is specifically intended to operate on a high-fidelity V2G system is proposed. The system consists of a combination of a grid synchronizing vector controller inverter, and a bidirectional DC-DC converter that is controlled by a Fuzzy Logic Controller (FLC) to manage a battery. The contribution of this work is twofold: a viable DC-based architecture enabling robust power transfer is presented for the V2G system. Second, the designed combined d-q and fuzzy logic controller scheme is shown to reduce the harmonic distortion as evidenced by thorough simulations and comparisons with previous work on this task. The paper is structured as follows, Section 2 presents a review of past literature. Section 3 explains the research methodology, which includes the proposed system design and the simulation models of each unit. The results, along with a comparison of previous work, are presented in Section 4, while the conclusion and future work are presented in Section 5.

## 2. Literature Review

The work in [4] presents a scheme for electric vehicles in building energy systems, focusing on DC microgrid-based charging stations. The authors proposed a unified architecture where a solar photovoltaic system, a stationary storage battery, the grid, and the electric vehicle were controlled as a single energy ecosystem. They utilized an artificial neural network (ANN) based adaptive controller to control power circulation for both the vehicle-to-grid and grid-to-vehicle scenarios. This system focuses on the exploitation of solar generation and stationary storage with strategic use of the EV battery as

supplementary power in case of power deficit or if there is a surplus energy supply. The authors demonstrate that their ANN-based controller not only effectively manages the complex power exchanges but also significantly enhances the DC bus voltage regulation, in that the voltage overshoot was reduced, and the transient response times were improved. The work in [6] uses optimization schemes to optimize the core grid services of V2G. In this work, the task of valley filling and peak shaving is formulated as a direct control problem, and a specific V2G control approach is created based on an objective function. The proposed controller aimed to optimally schedule the charging and discharging of a connected EV fleet to transform the load profile of the grid to a desired profile. They also studied power quality issues that were created by high-power charging infrastructure. Measurements in full charging cycles were conducted in [7], where the harmonic amplitudes and phase angles of each harmonic were measured and compared to IEEE 519 [8] and IEC 61000 standards. Although the charger analyzed was within the general voltage Total Harmonic Distortion limits, individual higher-order harmonics did exceed the individual component limits. More importantly, the authors established that the phase angle of multiple chargers on the same feeder gets harmonized, causing their distortions to be additive instead of being cancelled.

The work in [9] conducted an analysis at a smart grid testing facility utilizing a reconstructed distribution network to evaluate a bidirectional charging station. In their study, the authors measured harmonic and supraharmonic emissions, high-frequency grid impedance, efficiency, and power factor across operating points. They revealed that as the unit exhibited high efficiency, a strong power factor, and low current distortion at its nominal 10kW rating, these metrics degraded significantly at lower power levels. Another study by [10] assessed how harmonic currents from aggregated charging stations accelerate the aging and increase losses in distribution transformers. The analysis applied a weighted arithmetic mean to account for the dynamic state-of-charge of EV batteries, thereby achieving a more accurate projection of long-term transformer stress. To evaluate system-wide effects, the authors employ a fast-decoupled harmonic power flow on a modified IEEE 33-bus test system embedded with multiple EV parking lots. Crucially, the paper proposed a mitigation framework in the form of a novel optimal harmonic power flow algorithm. The presented method ensured photovoltaic-based distributed generation units not only provided reliable energy but also performed compensation of harmonics actively so as to improve voltage profile and extend the lifespan

of the transformer. The authors in [11] analyze harmonic distortion of multiple electric vehicles and their chargers using Matlab on real-time power data. Another study was performed by [12] who analyzed the total harmonic distortion of a multifunctional converter for electric vehicles. Following their analysis, they present an architecture of a multifunctional converter with soft switching, low magnetizing current and minimum switching losses. Furthermore, in [13], the authors address harmonic mitigation by suggesting the usage of a shunt active power filter (SAPF) based electric vehicle charging system. Their suggested scheme ensures that the DC link voltage is efficiently regulated. The work in [14] examined a detailed power quality footprint by testing eight different EV models. Their methodology involved incrementally increasing the charging current to map the relationship between the power level and harmonic generation. They found that harmonic distortion intensifies at lower charging currents, a common scenario in prolonged smart charging sessions. The analysis scaled this insight using Monte Carlo simulations to model multi-vehicle charging, revealing that while some harmonic cancellation occurs in aggregate, their scenario produced a total current THD of 25%, with many vehicles exceeding individual harmonic limits.

The work in [15] proposed an improved parameter identification mechanism that fuses numerical and analytical techniques, specifically using the nonlinear Shepherd model. Their core innovation was the application of a meta-heuristic, the Marine Predator Algorithm (MPA) [16], to extract dynamic parameters from outdoor operational data. The study benchmarked the MPA against several contemporary optimizers, including the Salp Swarm Algorithm [17] and the Honey Badger Algorithm [18], in terms of convergence speed and identification accuracy. The results demonstrated that the MPA achieved exceptional identification efficiency for the tested battery types. The study in [19] presented an advanced co-optimization framework that seeks to optimize a hybrid photovoltaic battery system combining a Binary Waterwheel Plant Optimization [20] algorithm for converter control with a Temporal Inductive Path Neural Network [21] for load forecasting and power quality correction. In their results, the authors report a reduced Total Harmonic Distortion and a low leveled cost of energy and net present cost.

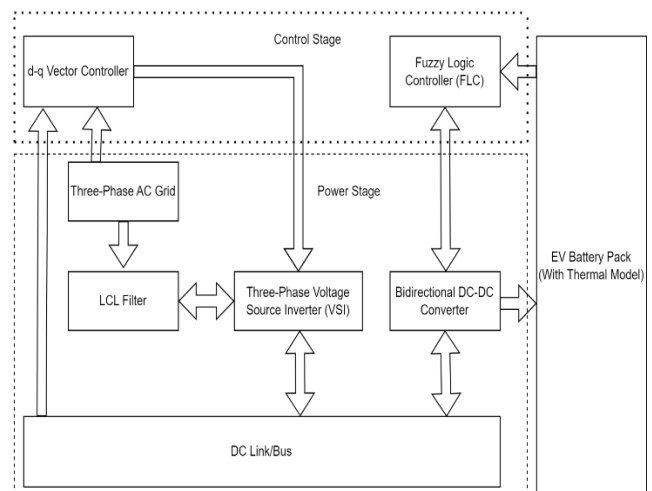
Work in [22] compared the performance of conventional and fractional-order PI/PID controllers, optimized by AI techniques, including artificial neural networks and Reinforcement Learning. In their work, they tested these AI-tuned controllers with dynamic EV charging loads for a 22-kW vehicle. Their results

indicate that while AI-tuning improves all controller types, the greatest benefit is realized with the Fractional-Order PID structures. The AI-optimized FOPID controller achieved superior voltage regulation with minimal overshoot. The study in [23] proposed a refined control strategy integrating Sinusoidal Pulse Width Modulation with a Proportional-Integral controller tuned using the established Ziegler-Nichols method. The presented approach aimed to maintain a stable voltage-to-frequency ratio under dynamic loads, thereby targeting harmonic generation at its source. In their results, they were successful in reducing Total Harmonic Distortion while improving torque stability and speed regulation.

### 3 Methodology

#### 3.1 Proposed System

The proposed Vehicle-to-Grid (V2G) system is implemented as a grid-integrated DC fast-charging station with the potential to flow power in both directions. The proposed system architecture, as shown in Figure 1, includes the AC power grid, a power conditioning interface, which constitutes the power stage, the designed d-q and fuzzy logic controller for power control and thermal regulation, as well as the electric vehicle (EV) battery storage. These stages are discussed in this section.



**Fig. 1.** Overview of the proposed system

#### 3.2 Grid Interface and Power Conditioning

The connection to the three-phase AC utility grid forms the system's foundation. Power is provided at a normal distribution voltage. An LCL filter is placed between the converter and the grid. The filter is necessary to reduce switching harmonics at higher frequencies caused by the power electronics, so as to ensure that the current injected into or drawn off the grid meets the requirements of power quality. The conversion of power is done in two steps. First, a grid-tied, three-phase Voltage Source Inverter (VSI) controls the flow of power between the DC bus and

the AC grid. Second, a bidirectional DC-DC converter is also incorporated, which controls the flow of energy between the DC bus and the EV battery pack.

### 3.3 Bidirectional DC-DC Converter and Fuzzy Logic Controller

The bidirectional converter is the primary interface for battery management. It operates in two distinct modes during system operation. Buck Mode (G2V Charging): In this mode, the converter steps down the DC bus voltage to the battery charging level. The power flows from the grid to the vehicle (G2V). The battery management interface is provided by the bidirectional converter. There are two modes of operation of the system. In the Buck mode (G2V Charging), the converter reduces the DC bus voltage to the charging level of the battery. The vehicle (G2V) receives the power flowing out of the grid. During discharging, the converter operates in Boost Mode (V2G Discharging) to step up the battery voltage to the higher DC bus level, enabling power flow from the vehicle to the grid (V2G).

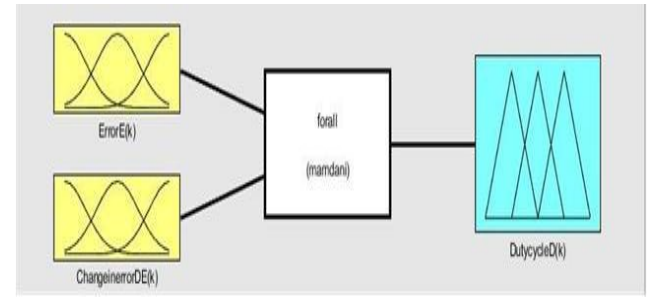
A Fuzzy Logic Controller (FLC) is used to control the operation of the bidirectional converter. The designed FLC uses triangular member function with the parameters shown in Figure 2. As inputs, it takes the difference between the reference and measured current of the battery. It then creates a control signal to the bidirectional converter using fuzzification, performs inference and outputs a control signal after defuzzification. This ensures a controller performance with low dynamic response time and reduced output ripple.

Triangular membership functions were chosen for their computational simplicity and ease of interpretation. They have been proven to facilitate fast processing, which is necessary for real-time applications as is the case with EV systems. Moreover, due to their construction, the triangular membership functions used allow for dynamic adjustment of the control action to changing conditions without a large computational overhead.

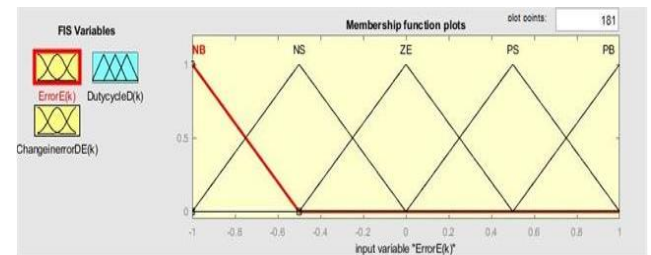
### 3.4 Electric Vehicle and Battery Model

The EV is fundamentally modeled as a large-capacity battery energy storage system (BESS). One of the essential elements is the consideration of battery degradation dynamics, that is, temperature effects. The parameters which depend on temperature include the battery's internal resistance, the voltage and its current capacity. The battery model also incorporates the thermal behavior associated with battery operation

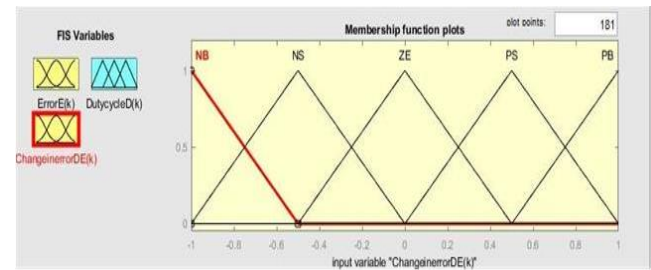
including heat generation, and transfer dynamics. These parameters are incorporated to allow for simulating real-world effect of variable cell temperature of power flow stability and to assess the battery's harmonic performance.



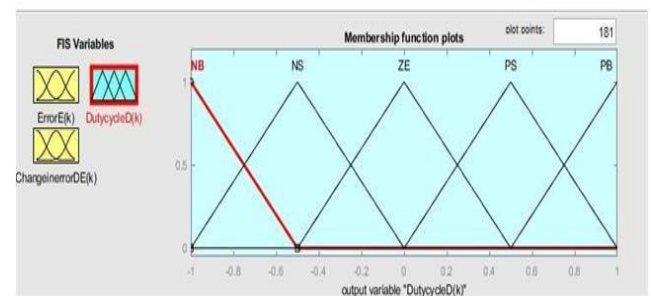
(a)



(b)



(c)



(d)

**Fig. 2.** (a) Fuzzy design, triangular MFs. (b) Error  $E(k)$ . (c) Change in error  $DE(k)$ . (d) Duty cycle  $D(k)$

### 3.5 Inverter Vector Control Strategy

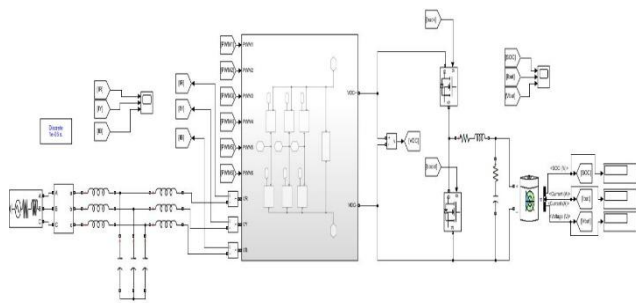
In order to manage the power exchange on the grid side, a decoupled control strategy in the synchronous (d-q) reference frame is used for the VSI. A cascade control structure is employed where a constant DC-link voltage is maintained by the other voltage control loop. An inner control loop regulates the active (d-axis) and reactive (q-axis) current components that are injected into the grid. This design scheme allows to control both the active and reactive power

independently. Furthermore, both feed-forward and decoupling terms are included to enhance transient response and stability. The controller ensures seamless transition between G2V and V2G modes while maintaining grid synchronization and high-power quality.

The integrated operation of all these units is managed by coordinated action of both controllers. The d-q controller maintains grid synchronization and DC-link voltage while the FLC manages the battery current based on the mode (charge/discharge). When grid power is available for charging (G2V), the FLC drives the bidirectional converter in buck mode whereas when grid support is required (V2G), the FLC switches the converter to boost mode, and the inverter control adjusts to export power. Throughout this process, the LCL filter minimizes harmonic distortion in the grid current. In this manner, power stability is ensured.

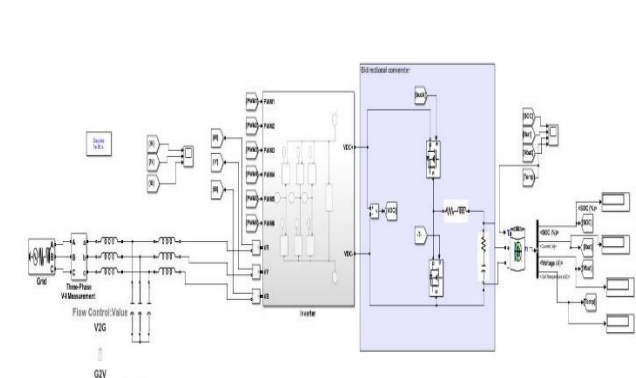
#### 4. Simulation Models

The current section details the simulation setup for the proposed system. The model of the DC fast-charging architecture, coupled with the V2G-G2V system as presented in Figure 1, along with the dual control mechanism, was simulated in Simulink. The V2G -G2V model is shown in Figure 3.



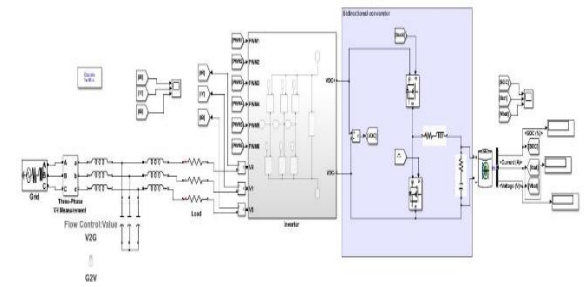
**Fig. 3.** Simulation Model of the V2G-G2V system

It comprises grid, an LCL filter, an inverter, a bidirectional converter, a battery, and controllers. Furthermore, the simulation model of the V2G -G2V model at variable cell temperature is shown in Figure 4.

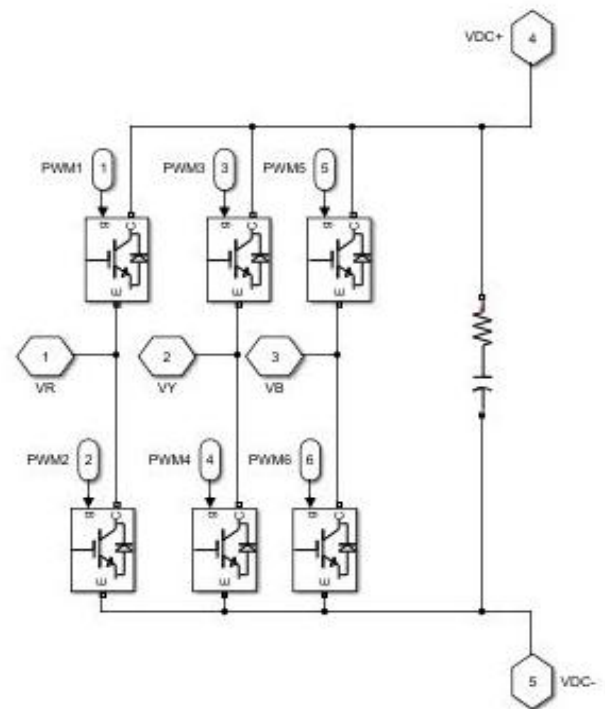


**Fig. 4.** Simulation model of the V2G-G2V system at variable cell temperature

The simulation model of the V2G -G2V model with load is shown in Figure 5. The simulation model of the inverter is shown in Figure 6.

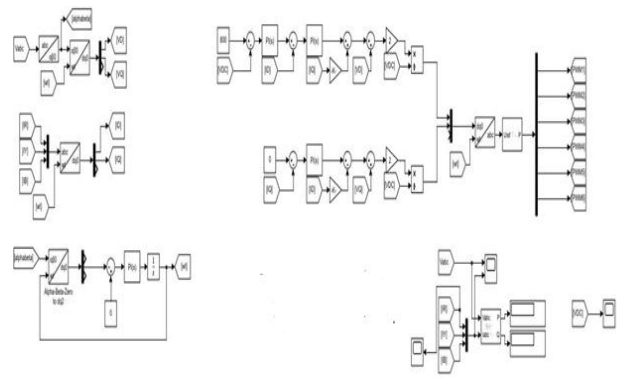


**Fig. 5.** Simulation Model of the V2G-G2V system with Load

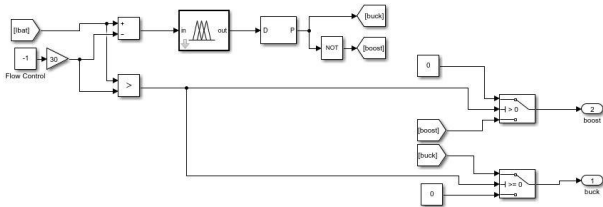


**Fig. 6.** Simulation Model of the Inverter

Furthermore, the control circuits with the inverter and bidirectional converter are shown in Figures 7 and 8. These enable bidirectional power exchange between the grid and EVs using the devised control method for the power electronic interface.



**Fig. 7.** Simulation model of the vector controller for the inverter



**Fig. 8.** Simulation model of the Fuzzy Logic Controller for the Bi-directional Controller

## 5. Results

The model was simulated with the parameters listed in Tables 1 and 2, derived from real-world operational considerations as given in [12, 24]. Simulations were performed under normal conditions, battery cell temperature variation, and under load, with the THD analyzed over three operational conditions. The simulation was performed for 1 second which is sufficient to observe both the transient as well as steady state behavior of the system. Furthermore, a sampling rate of 1000 Hz was used.

**Table 1**

Grid Parameters with LCL Filter

| Grid Parameters        | Values     |
|------------------------|------------|
| Phase-to-phase voltage | 415V       |
| Source resistance      | 0.8929e-3Ω |
| Frequency              | 50Hz       |
| Source inductance      | 16.58e-9 H |
| <b>LCL parameters</b>  |            |
| Inductance             | 5e-3       |
| Capacitance            | 30 e-6     |
| Inductance             | 5e-3       |

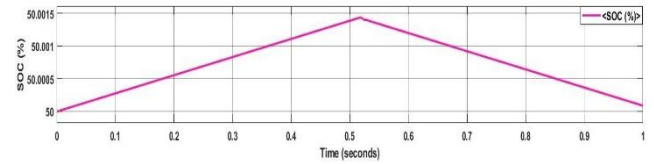
**Table 2**

Battery parameters with Bidirectional Converter

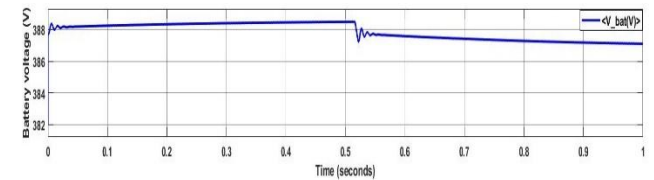
| Battery with bidirectional converter      | Values   |
|-------------------------------------------|----------|
| Nominal voltage                           | 360V     |
| Rated Capacity                            | 300 Ah   |
| Initial state of charge                   | 50       |
| <b>Bidirectional converter parameters</b> |          |
| Inductance                                | 20e-3    |
| Capacitance                               | 0.625e-6 |
| Inductance                                | 5e-3     |

The EV batteries' initial state of charge (SOC) is set at 50%. The SOC waveform is shown in Figure 9. Initially, power flows from the grid to the vehicle from

0 to 0.52s, with the battery charging during this time. After 0.53s, the battery starts to discharge. The battery voltage is shown in Figure 10. It can be observed that the battery voltage is 388V from 0 to 0.52s, and it starts to decrease during the discharging phase as expected.

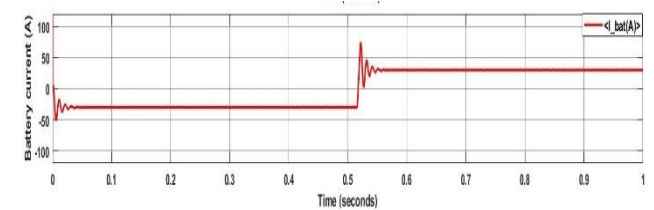


**Fig. 9.** SOC Waveform

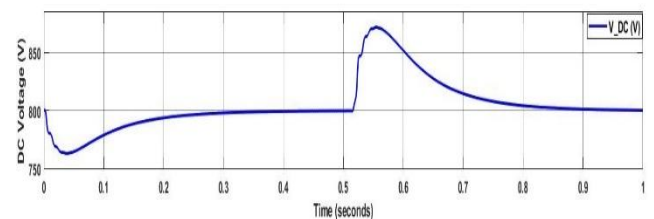


**Fig 10.** Battery Voltage

The plot for the current drawn from the battery is shown in Figure 11. From 0 to 0.52s, the battery current is -30A during charging. The battery current increases to 30A during discharge as current is drawn from it. The DC voltage is approximately 800 V in the bus is 800 V and peaks at 850 V when discharging starts, as shown in Figure 12. It stabilizes to 800 V again due to the PID controller employed.

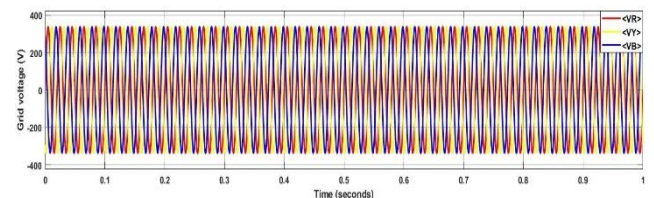


**Fig. 11.** Battery Current

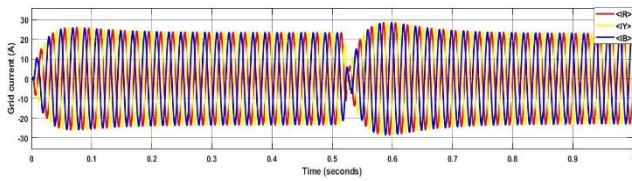


**Fig. 12.** DC Voltage

The PID controller is used to maintain a constant DC voltage. The FLC provides the control for reducing the ripple and the rise time in the output by performing dynamic control action to make the system stable. The resulting grid voltage and grid current are shown in Figures 13 and 14.

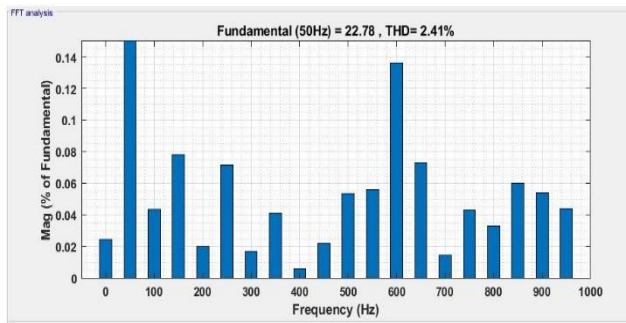


**Fig. 13.** Grid Voltage



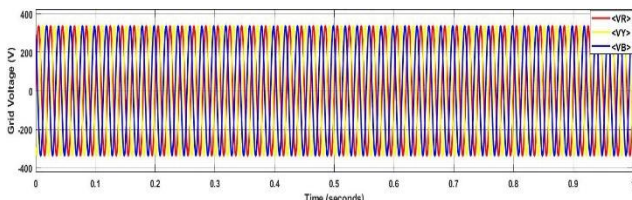
**Fig 14.** Grid Current

It is observed that the grid current decreases at the instant of 0.52s when battery charging is stopped and discharging starts. This triggers the d-q controller, which maintains the grid current. It can be observed that the developed d-q controller enables smooth power transfer between the EV and the grid. Both the modified active power reference and the DC bus voltage are tracked sufficiently well, resulting in a stable supply of power and good dynamic performance. The total harmonic distortion of the grid when current is injected into it is shown in Figure 15. It can be observed that the designed d-q FLC combination in conjunction with the LCL filter results in a THD of 2.41% for grid-injected current at various frequencies. This is lower than the 5% allowable limit of the IEEE 1547 standard.

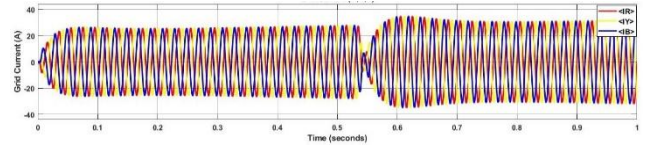


**Fig. 15:** THD Result for Grid Current

Battery temperature is another parameter that can impact the THD in a V2G-G2V system. To study this impact, the simulation was run while increasing battery temperature from 0-40 degree Celsius. The voltage in the grid during this temperature change is shown in Figure 16. It can be observed that at variable temperature, the grid voltage is approximately constant during both modes of operation, from G2V and V2G. Figure 17 shows the grid current at cell temperature. It can be observed that during the G2V mode from 0 to 0.54s, the grid current is constant. During V2G mode, grid current increases from 0.54s to 1 s. Importantly, it can be observed that the designed fuzzy logic controller maintains the grid current at variable cell temperature.

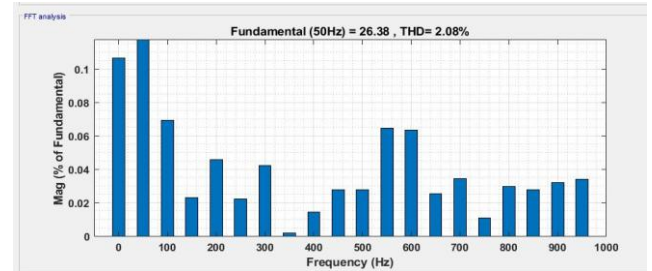


**Fig. 16.** Grid Voltage at Cell Temperature



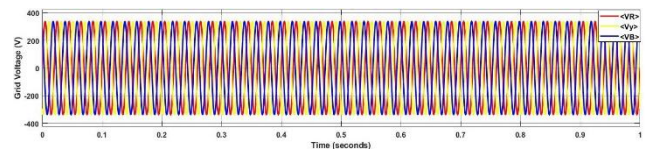
**Fig. 17.** Grid Current at Cell Temperature

Fig. 18 shows the THD level of grid-injected current while considering cell temperature. It can be observed that the d-q and FLC controller combination maintains the grid current effectiveness while minimizing the THD. It effectively maintains the THD of the system. The THD was found to be 2.08% for a grid-injected current of 26.38A.

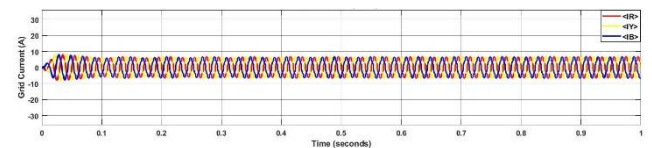


**Fig. 18.** THD Result of Grid Current at Cell Temperature

In the next experiment, the proposed system design is tested by considering the effect of load. As in previous experiments, the impact of load has been analyzed through grid current and grid voltage. Figure 19 shows the grid voltage at the load. Grid voltage is approximately constant during both modes of operation, that is, G2V and V2G, with the load. Figure 20 shows the grid current observed during the simulation. With the addition of load, the grid current decreases to 6.424 A.

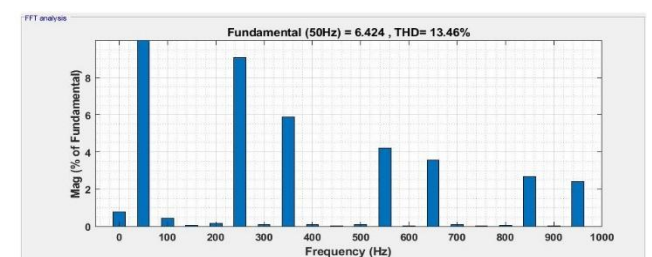


**Fig. 19.** Grid Voltage with Load



**Fig. 20.** Grid Current with Load

Figure 21 shows the THD level of the grid-injected current with the load. The THD level can be seen as increasing to 13.46% for injected grid current.



**Fig. 21.** THD result of grid current with Load

Table 3 summarizes the results of the three experiments performed. It can be observed from the table that for all scenarios considered, the achieved THD levels fall within acceptable levels. Moreover, statistical testing was performed after multiple simulation runs and the THD levels for all experiments were found to be within the 95% confidence interval.

**Table 3**

THD levels achieved for the various experiments

| Experiment                     | THD Levels Achieved |
|--------------------------------|---------------------|
| Normal (Grid Injected Current) | 2.41%               |
| Battery Temperature Variation  | 2.08%               |
| With Load                      | 13.46%              |

In order to validate the performance of the proposed combined d-q FLC controller, the proposed system is compared with previous works, as shown in Table 4. In [7], the grid harmonic effect on the charging of multiple EVs has been analyzed, with a THD of 5.5% being achieved. In [9], the high-frequency grid impedance and the harmonic and supraharmonic emissions of a bidirectional EV were considered with, a THD of 3.8% being achieved. In [10], PV-based distribution units with EV are analyzed. The THD was found to be 2.45%. In [11], a smart charging system for EVs was implemented. And the THD was to be 25%. It can be observed that the proposed d-q FLC controller design results in lower total harmonic distortion, thereby offering a reliable scheme for enhancing power quality in EV systems. The proposed controller design not only surpasses previous solutions in reducing THD.

**Table 4**

Comparative Analysis of THD Levels

| References | THD levels |
|------------|------------|
| [7]        | 5.5%       |
| [9]        | 3.8%       |
| [10]       | 2.45%      |
| [14]       | 25%        |
| Proposed   | 2.41%      |

## 6. Conclusion and Future Work

Electric vehicles (EVs) contribute an important role in the transition toward cleaner and more sustainable energy sources. However, battery degradation parameters impact the performance of the system. In this regard, this paper proposes a novel

architecture for implementing a V2G–G2V system with d-q and FLC. By absorbing surplus energy from the grid during Grid-to-Vehicle operation and supplying energy back during Vehicle-to-Grid mode through the designed d-q controller FLC combination, effective grid energy management is performed. The results from the simulation of the proposed system indicate stable bidirectional power transfer between the grid and the vehicle. It was observed that the designed d-q and FLC combination was successfully able to maintain the battery performance while limiting THD within IEEE standards. The proposed controller achieved a low harmonic distortion of 2.41% during current injection in the grid while achieving strong dynamic performance and maintaining stable DC bus voltage. In addition, at variable cell temperature, a THD of 2.08% was observed. Lastly, comparison with previous work indicates the superior performance of the proposed system design during G2V–V2G operation. In conclusion, the current system was observed to perform robustly and will be useful for smart grid integration within EV systems. The designed system will contribute to the efficient utilization of power in the smart grid by allowing for better integration of renewable energy sources thereby also reducing greenhouse gas emissions in the long term. Furthermore, it will also enhance grid stability with the transport of power through the grid. Lastly, by nature, this system will spur further development of the smart grid system.

While the current work presents a robust system for power exchange between an EV and the grid, there are various avenues of future work, the current design could be extended for multi-EV fleet coordination for power transfer stability analysis. However, a point of concern would be delays in communication and data synchronization and fair load distribution which would need to be resolved before system testing. Another avenue of future work is resilience testing and hardware in the loop testing.

## 7. References

- [1] Rezaee, Saeed, Ebrahim Farjah, and Benyamin Khorramdel. "Probabilistic analysis of plug-in electric vehicles impact on electrical grid through homes and parking lots." *IEEE Transactions on Sustainable Energy* 4, no. 4 (2013): 1024-1033.
- [2] Ma, Yuchao, Tom Houghton, Andrew Cruden, and David Infield. "Modeling the benefits of vehicle-to-grid technology to a power system." *IEEE Transactions on power systems* 27, no. 2 (2012): 1012-1020.

- [3] Habib, Salman, and Muhammad Kamran. "A novel vehicle-to-grid technology with constraint analysis-a review." In 2014 international conference on emerging technologies (ICET), pp. 69-74. IEEE, 2014.
- [4] Singh, Abhishek Pratap, Yogendra Kumar, Yashwant Sawle, Majed A. Alotaibi, Hasmat Malik, and Fausto Pedro Garcia Marquez. "Development of artificial Intelligence-Based adaptive vehicle to grid and grid to vehicle controller for electric vehicle charging station." *Ain Shams Engineering Journal* 15, no. 10 (2024): 102937.
- [5] Wang, Zhenpo, and Shuo Wang. "Grid power peak shaving and valley filling using vehicle-to-grid systems." *IEEE Transactions on power delivery* 28, no. 3 (2013): 1822-1829.
- [6] Attou, Nasreddine, Sid-Ahmed Zidi, Samir Hadjeri, and Mohamed Khatir. "Improved peak shaving and valley filling using V2G technology in grid connected Microgrid." In 2021 Third International Conference on Transportation and Smart Technologies (TST), pp. 53-58. IEEE, 2021.
- [7] Lucas, Alexandre, Fausto Bonavitacola, Evangelos Kotsakis, and Gianluca Fulli. "Grid harmonic impact of multiple electric vehicle fast charging." *Electric Power Systems Research* 127 (2015): 13-21.
- [8] Duffey, Christopher K., and Ray P. Stratford. "Update of harmonic standard IEEE-519: IEEE recommended practices and requirements for harmonic control in electric power systems." *IEEE Transactions on industry applications* 25, no. 6 (2002): 1025-1034.
- [9] Grasel, Bernhard, José Baptista, and Manfred Tragner. "Supraharmonic and harmonic emissions of a bi-directional V2G electric vehicle charging station and their impact to the grid impedance." *Energies* 15, no. 8 (2022): 2920.
- [10] Alame, Dima, Maher Azzouz, and Narayan Kar. "Assessing and mitigating impacts of electric vehicle harmonic currents on distribution systems." *Energies* 13, no. 12 (2020): 3257.
- [11] Bala, Anju, Ritula Thakur, and Shimi Sudha Letha. "Harmonic Distortion Analysis of Electric Vehicle Charging Using Real-Time Data." In 2024 2nd International Conference on Advancements and Key Challenges in Green Energy and Computing (AKGEC), pp. 1-5. IEEE, 2024.
- [12] Jain, Rakhee, and Dheeraj Agrawal. "Total Harmonic Distortion of Multifunctional Converter for Electric Vehicles." In 2024 IEEE 2nd International Conference on Innovations in High Speed Communication and Signal Processing (IHCS), pp. 1-5. IEEE, 2024.
- [13] Srivastava, Abhishek, and S. Saravanan. "Harmonic mitigation using optimal active power filter for the improvement of power quality for a electric vehicle changing station." *e-Prime-Advances in Electrical Engineering, Electronics and Energy* 8 (2024): 100527.
- [14] Senol, Murat, I. Safak Bayram, Lewis Hunter, Kristian Sevdari, Connor McGarry, David Campos Gaona, Oliver Gehrke, and Stuart Galloway. "Harmonics measurement, analysis, and impact assessment of electric vehicle smart charging." *IEEE Open Journal of Vehicular Technology* (2024).
- [15] Achaihou, Nadia, Seydali Ferahtia, Ali Djerioui, Aissa Chouder, Hegazy Rezk, and Azeddine Houari. "Optimal parameters identification strategy of a lead acid battery model for photovoltaic applications." *Energy Storage* 5, no. 4 (2023): e428.
- [16] Su, Ya, and Yi Liu. "A novel marine predator whale optimization algorithm for global numerical optimization." *Engineering Optimization* (2025): 1-37.
- [17] Aishwarya, R., and G. Mathivanan. "Improved salp swarm algorithm based optimization of mobile task offloading." *PeerJ Computer Science* 11 (2025): e2818.
- [18] Hashim, Fatma A., Essam H. Houssein, Kashif Hussain, Mai S. Mabrouk, and Walid Al-Atabany. "Honey Badger Algorithm: New metaheuristic algorithm for solving optimization problems." *Mathematics and Computers in Simulation* 192 (2022): 84-110.
- [19] Raja, Y. Anselem Benet, and A. Thangaraj. "Enhanced harmonic reduction and energy optimization in grid-connected photovoltaic-battery systems for improved power quality." *Journal of Energy Storage* 150 (2026): 120231.
- [20] Askar, Sami, S. Uma, Gaurav Sethi, M. Siva Ramkumar, and S. Dhivya. "Smart Grid Stability Enhancement using Waterwheel

Plant Algorithm for Demand Side Management." In 2025 7th International Conference on Inventive Material Science and Applications (ICIMA), pp. 379-385. IEEE, 2025.

- [21] Dong, Hao, Pengyang Wang, Meng Xiao, Zhiyuan Ning, Pengfei Wang, and Yuanchun Zhou. "Temporal inductive path neural network for temporal knowledge graph reasoning." *Artificial Intelligence* 329 (2024): 104085.
- [22] Gül, Ozan, and Jose Luis Dominguez Garcia. "Design and Evaluation of AI-Tuned Controllers for Three-Phase EV Charging Stations in Renewable Energy Grids." *IEEE Access* 14 (2026): 4970-4989.
- [23] Senol, Murat, and I. Safak Bayram. "Impact assessment and mitigation of electric vehicle smart charging harmonics." *IEEE Access* 13 (2025): 207412-207432.
- [24] Dursun, Mustafa, and M. Kenan DÖŞOĞLU. "LCL filter design for grid connected three-phase inverter." In 2018 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), pp. 1-4. IEEE, 2018.