Solar Energy Blended Main Grid and Hybrid Energy Storage System for Electric Vehicle Charging system

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Abstract
In addition to encouraging the use of renewable energy, a photovoltaic array connected to the main grid and a hybrid energy storage system for charging electric vehicles improves energy resiliency. The advantages of such a system can be maximised by careful planning and consideration of regional laws and incentives. The proposed plan for a hybrid energy storage system and photovoltaic array integrated with the main grid for electric vehicle charging was the major topic of this article. its primary elements, advantages, and factors to be considered. The design of an inverter with subsystem for integrating PV arrays with the main grid and hybrid energy storage systems was covered and implemented in this article to improve the efficiency of the electric vehicle charging system. Moreover, this paper attempted to use a suitable filter and its control algorithm to address power quality problems such as harmonic extraction and mitigation. By combining PV arrays with the main grid and hybrid energy storage systems, this research study demonstrates improved charging system performance through the use of MATLAB simulation and analysis of the results.

Keywords
Photo Voltaic (PV), Hybrid Energy Storage System (HESS), Electric Vehicle Charging System (EVCS),
Active Power Filter (APF), Phase Locked Loop (PLL)

I. INTRODUCTION

The increasing use of electric vehicles (EVs) calls for the construction of dependable, environmentally friendly, and effective charging infrastructure. Combining photovoltaic (PV) arrays, the main grid, and hybrid energy storage systems (HESS) for EV charging stations is one possible approach. This integrated system provides a clean, adaptable, and economical method of EV charging while addressing the issues of increased energy consumption, dependence on non-renewable resources, and the intermittent nature of renewable energy[1].

Solar energy is captured by a photovoltaic array and transformed into electrical power that may either be stored for later use or used directly to power EV chargers. Even in times of poor solar generation or heavy demand, the system can guarantee steady and dependable power by connecting this array to the Main Grid. To store extra solar energy, the Hybrid Energy Storage System integrates many storage technologies, including supercapacitors and lithium-ion batteries. In addition to stabilising the power supply, this storage maximises energy use, enabling quicker and more effective electric vehicle charging[2].

A dynamic and resilient energy ecosystem is produced by this integration, as seen in **Figure - 1**, which lessens the transportation sector's carbon footprint and reliance on the grid. This technology supports the shift to a more environmentally friendly, electrified future by improving the sustainability of EV charging infrastructure through the balance of energy generation, storage, and consumption. Additionally, the hybrid method enhances the overall energy security of the charging network and reduces expenses related to peak electricity use[3].

PV arrays, hybrid energy storage, and grid integration provide a scalable and creative way to fuel the electric vehicle revolution while lowering greenhouse gas emissions as the world transitions to a more sustainable future[1].

II. Scheme of PV Array integration with main grid and hybrid energy storage system for Electric Vehicle charing system

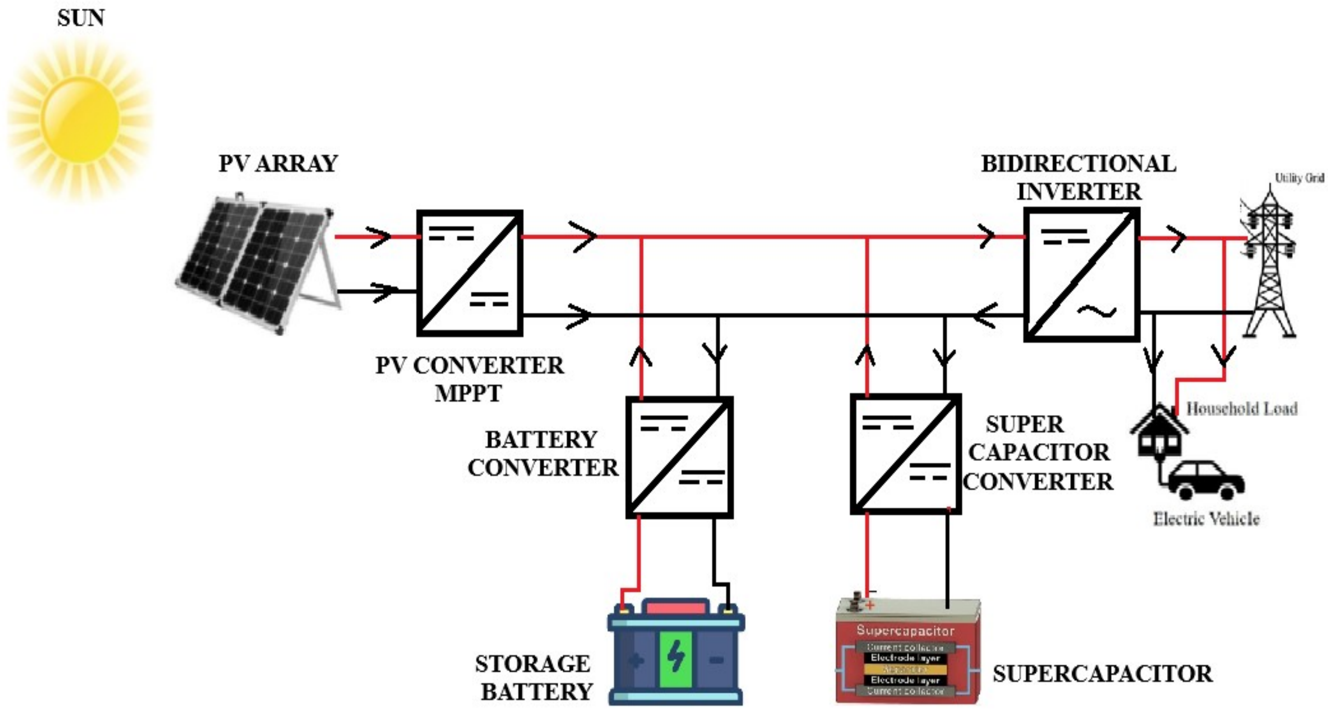


Figure – 1 Scheme of PV Array integration with main grid and hybrid energy storage system for EVCS

III. MAIN COMPONENTS, BENEFITS AND CONSIDERATIONS OF PV ARRAY INTEGRATED WITH MAIN GRID AND HESS FOR EVCS

- **Main Components:**
  - **PV Solar Panels**: Whether mounted on the ground or on a roof, these solar panels generate electricity.[4]
  - **Inverter**: The PV panels generate direct current (DC), which is transformed into alternating current (AC) that may be utilised by EV chargers and the grid.[4]
  - **Grid Connection**: Due to the system's connection to the power grid, energy can move both ways. When solar generation is not enough, energy can be taken from the grid and excess energy generated by the PV system can be delivered back to the grid.[4]
  - **EV Charging Station**: The system is connected to a Level 2 or Level 3 charger, which supplies the power required to charge EVs.[4]
  - **Energy Management System**: By determining when to charge EVs from the grid or the solar system based on demand, cost, and availability, this can optimise energy use.[4]

- **Benefits:**
  - **Reduced Energy Costs**: Lower energy costs result from using solar energy since it lessens dependency on the electrical grid.[5]
  - **Sustainability**: Reliance on fossil fuels and carbon emissions are decreased by using renewable energy.[5]
  - **Grid Support**: Overproduction of solar energy can aid in grid stabilisation, particularly during moments of high demand.[5]
  - **Energy Independence**: PV system owners can lessen their exposure to changes in the price of electricity.[5]

- **Considerations:**
  - **Initial Investment**: Although incentives and rebates may help reduce these costs, solar panels, inverters, and installation can have a substantial upfront cost.[6]
  - **Regulatory Environment**: The system's feasibility and financial viability are impacted by local incentives and laws.[6]
  - **Battery Storage**: By storing extra solar energy for use in the absence of sunlight, battery storage can improve the system's efficiency.[6]
  - **System Sizing**: For the PV system to satisfy the energy requirements of the EV charging station and any additional connected loads, proper sizing is essential.[6]
  - **Charging Speed**: The size of the PV system and the inverter capacity may restrict the charging pace, particularly in low-light conditions.[6]

IV. DESIGN OF INVERTER WITH SUBSYSTEM FOR THE INTEGRATION OF PV OUTPUT

An inverter is a device that converts DC to AC. Its input is the output of a boost converter, which converts DC to AC.[7] The reference signal is produced by the controller of the closed-loop system. This aids the inverter by providing gate pulses to the controller's switching device. Pulse width (PWM) and dq0-to-abc are employed. The MATLAB Simulink model for designing an inverter with a subsystem for integrating PV output is displayed in **Figure - 2.**[8]

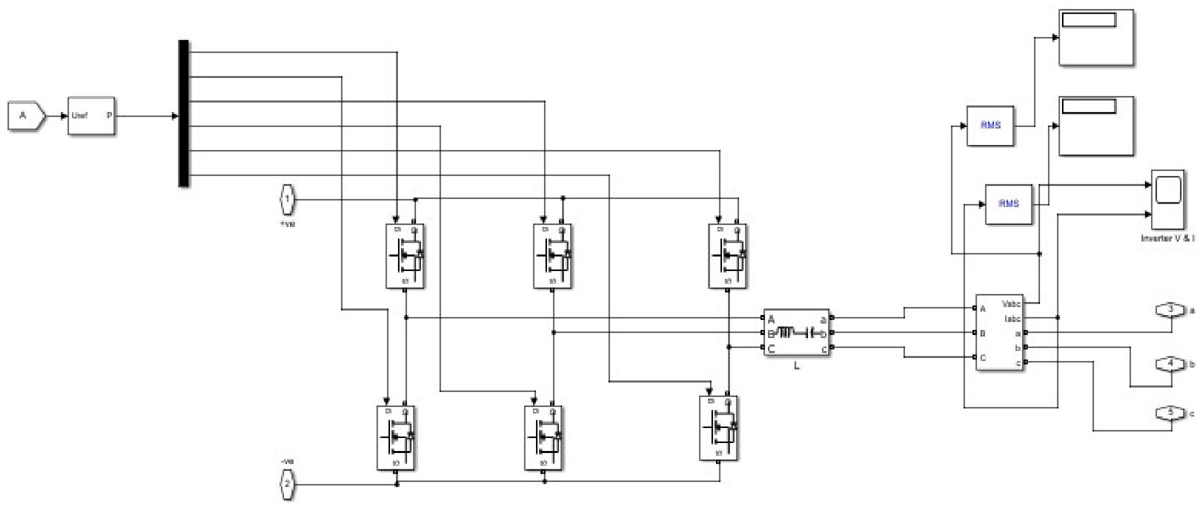


Figure – 2 MATLAB Simulink model for design of Inverter with Subsystem for the Integration of PV output

The gate pulses are produced using Pulse Width Modulation (PWM) and dq – to – abc. It uses the external voltage controller to calculate Vd, Vq, Id, and Iq. The MATLAB Simulink model for the ABC to dq control block is shown in **Figure - 3**, and the MATLAB Simulink model for the ABC to dq is shown in **Figure - 4.**[9]

Figure – 3 MATLAB Simulink model for abc-to-dq and control block

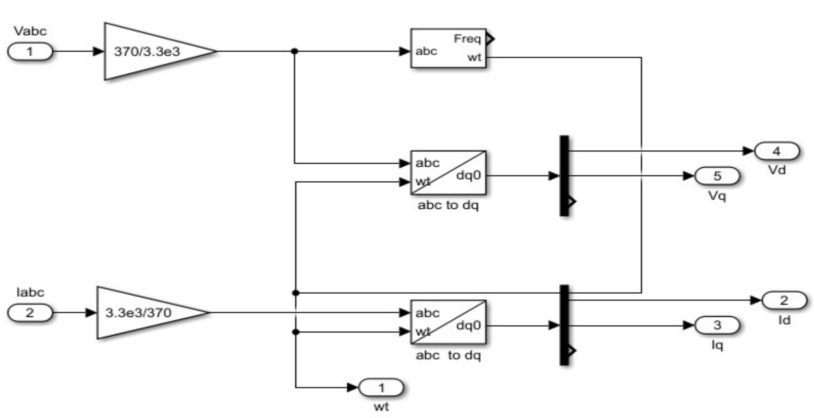
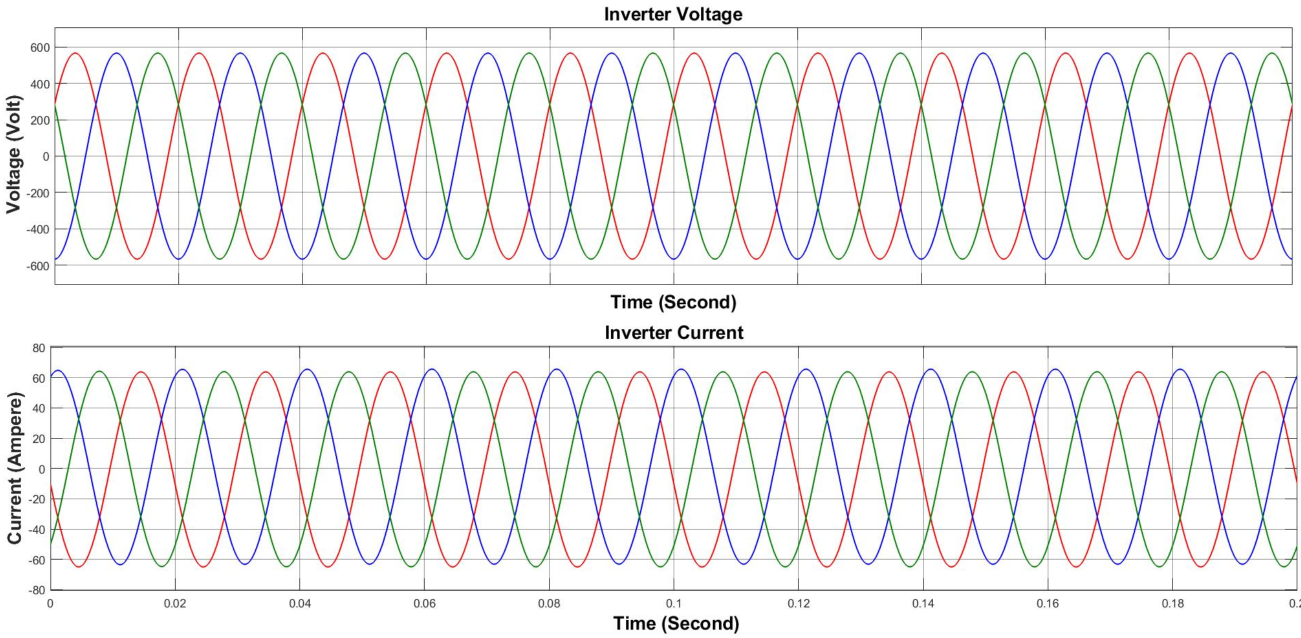


Figure – 4 MATLAB Simulink model for abc-to-dq

The gate pulses are produced using the dq-to-abc conversion and (PWM) technique. The control section uses the dc-link voltage and reference voltage to calculate idre f from the outside voltage controller, and then sets it to zero.[10]

- **Output of Inverter:**

Graph – 1 displays the inverter's output graph; it is a closed-loop system that regulates the inverter's voltage and current. The voltage is 550V and the current is 65A using PLL and dq transformation.[11]



Graph – 1: Inverter Output Voltage 550 Volts and Current 65 Amperes

IV. HARMONICS EXTRACTION AND MITIGATION WHILE CONNECTING THE PV ARRAY WITH BATTERY, SUPERCAPACITOR AND MAIN GRID

The park transformation (α-β-0 to d-q) and clerk transformation (a-b-c to α-β-0) both require APF. The dc source, inverter, coupling inductor, etc. are all contained within an active filter. Additionally, the inverter in the active power filter requires specific control topologies. The MATLAB Simulink model of a shunt active power filter is displayed in **Figure - 5.**[12]

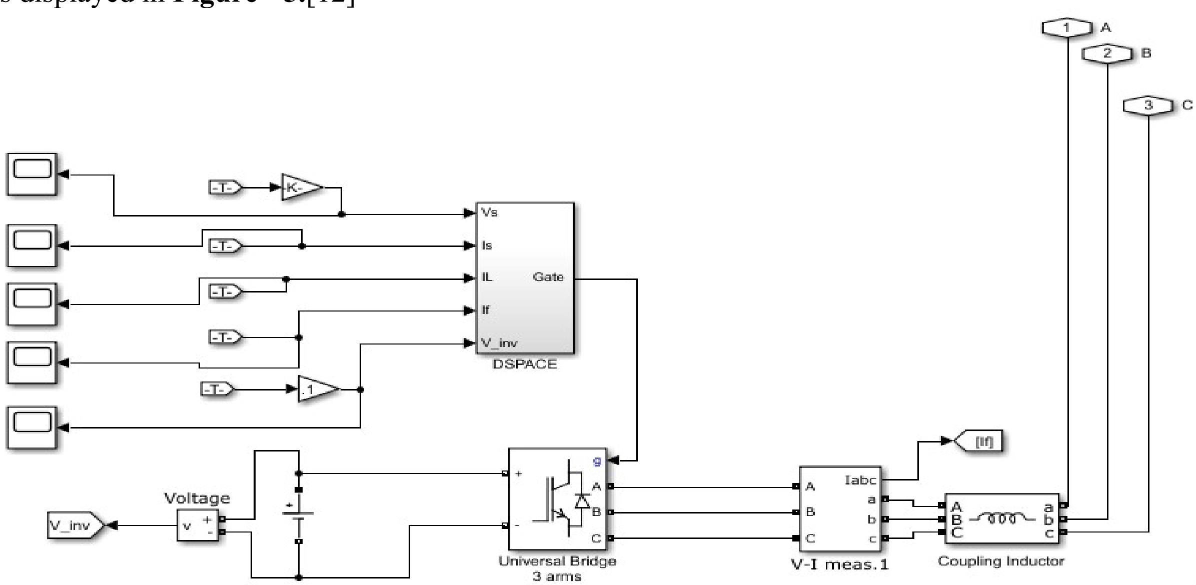


Figure – 5 MATLAB Simulink model of Shunt Active Power Filter (APF)

Vs = 400/1.732, f = 50 Hz and Vi/p = Inverter input voltage = 400 V.
Figure – 6 shows MATLAB Simulink model of subsystem of Shunt Active Power Filter

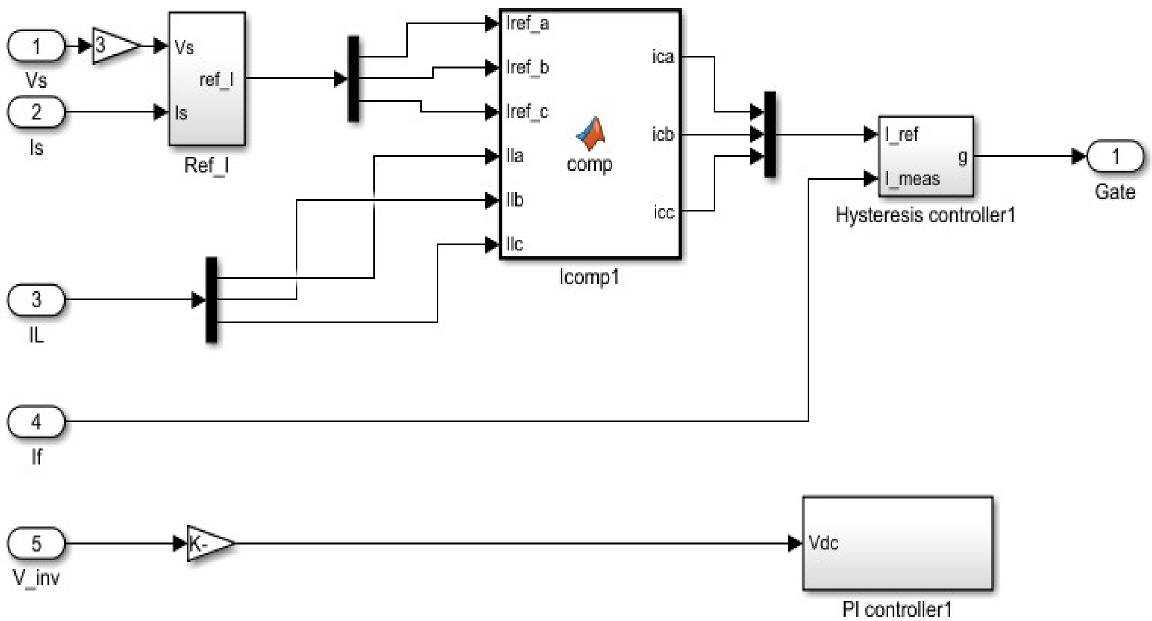
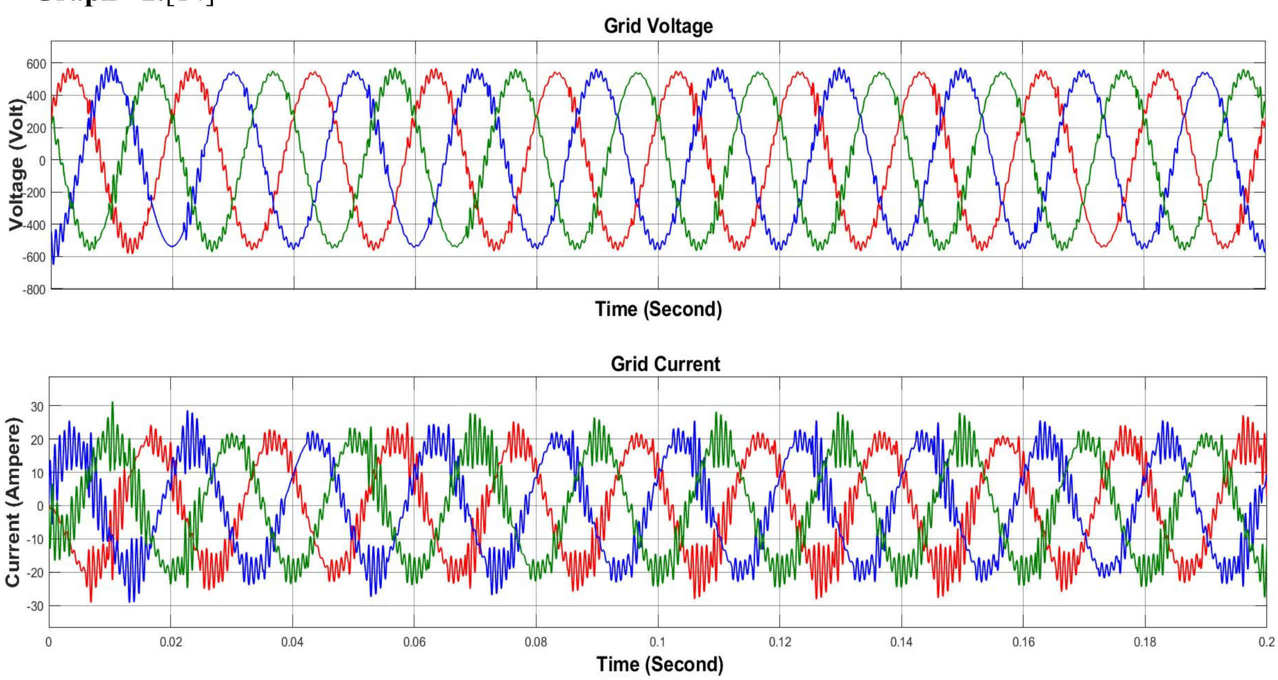


Figure – 6 MATLAB Simulink model of Sub system of Shunt Active Power Filter (APF)

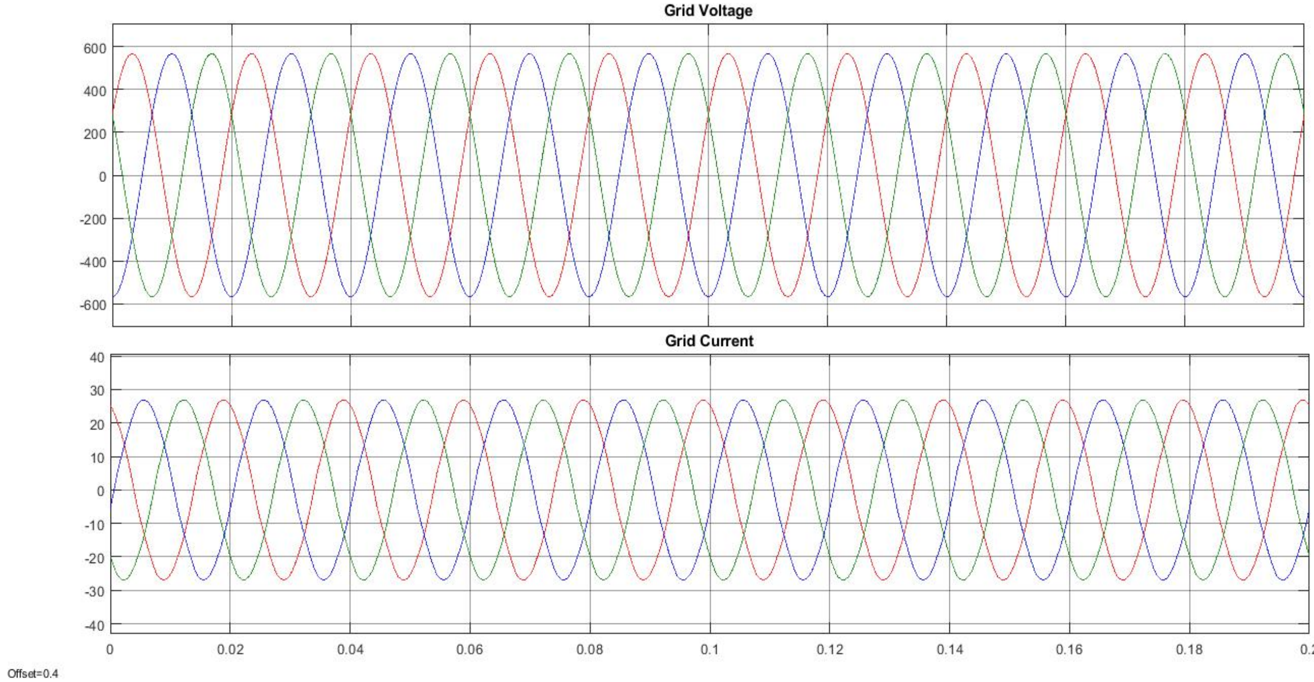
V. THD (TOTAL HARMONIC DISTORTION) ANALYSIS

The micro grid model is simulated using non-linear demand. The power system loads connected to the micro grid are nonlinear and produce sufficient harmonics. The main source of harmonics is power electronics device switching.[13] The simulation results and the THD computation utilising a Shunt APF are displayed in the accompanying figures. THD of Voltage is [2.99%] and THD of Current is [36.30%]. Shunt Active Power Filter not used. Grid voltage and current waveforms without filters are displayed in **Graph - 2.**[14]



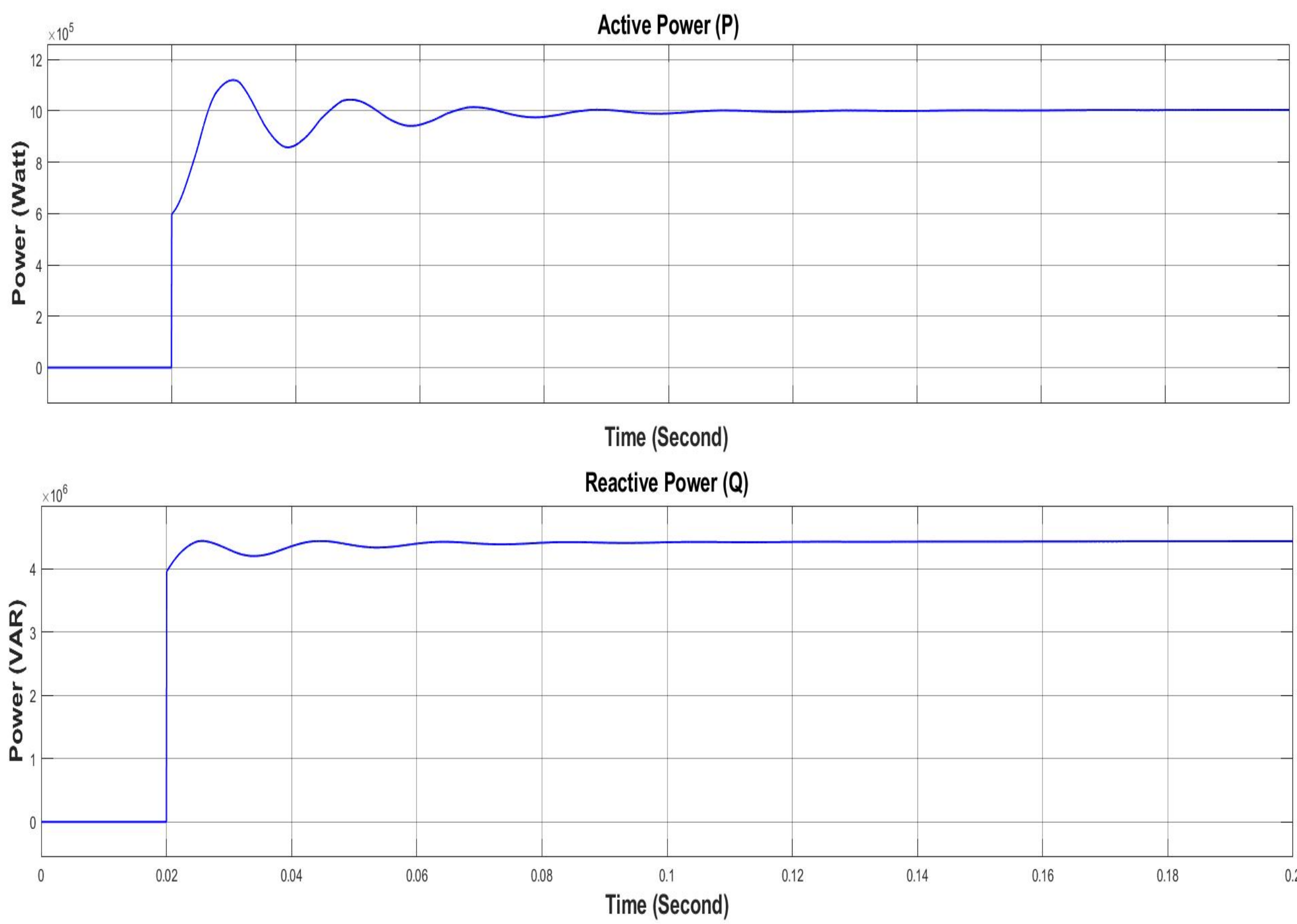
Graph – 2: Grid Voltage and Current waveform without filter

Graph – 3 displays the waveform of grid voltage and grid current using a shunt active power filter.



Graph – 3: Grid Voltage & Current with Shunt Active Power Filter

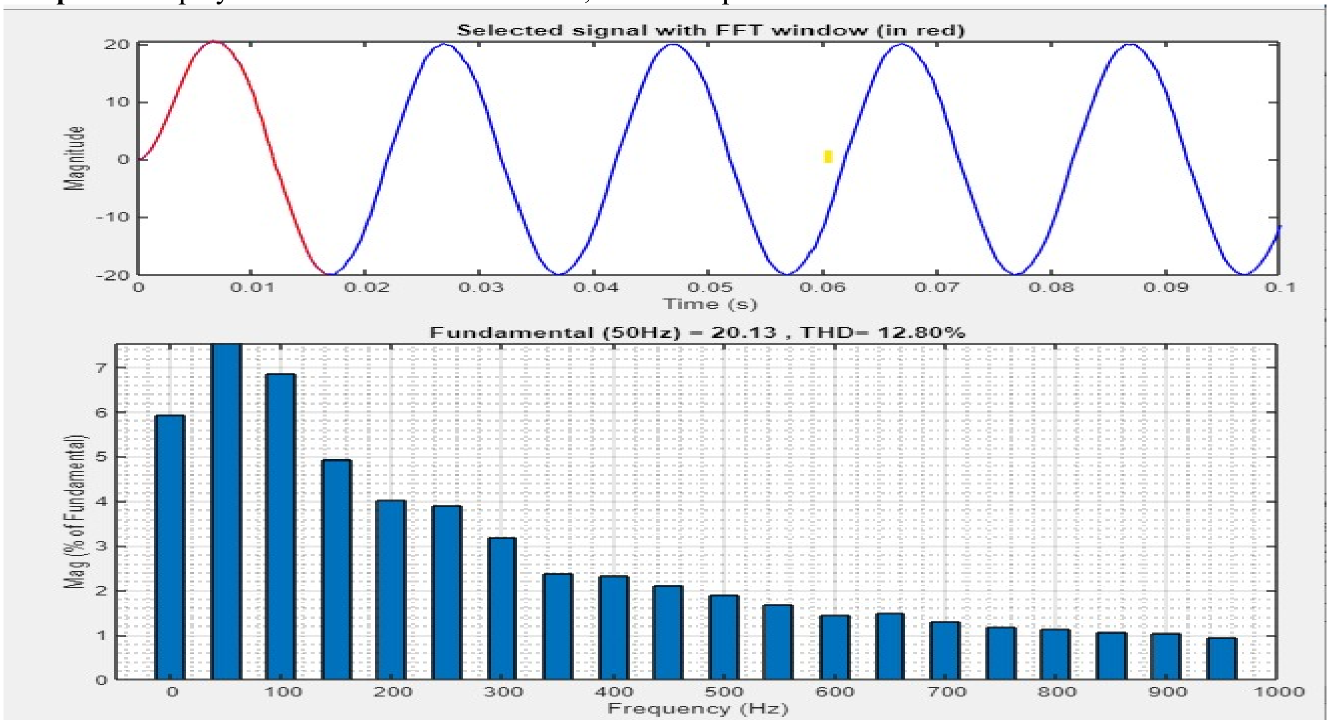
Graph – 4 displays the grid's reactive and active power.



Graph – 4: Active Power & Reactive Power of Grid

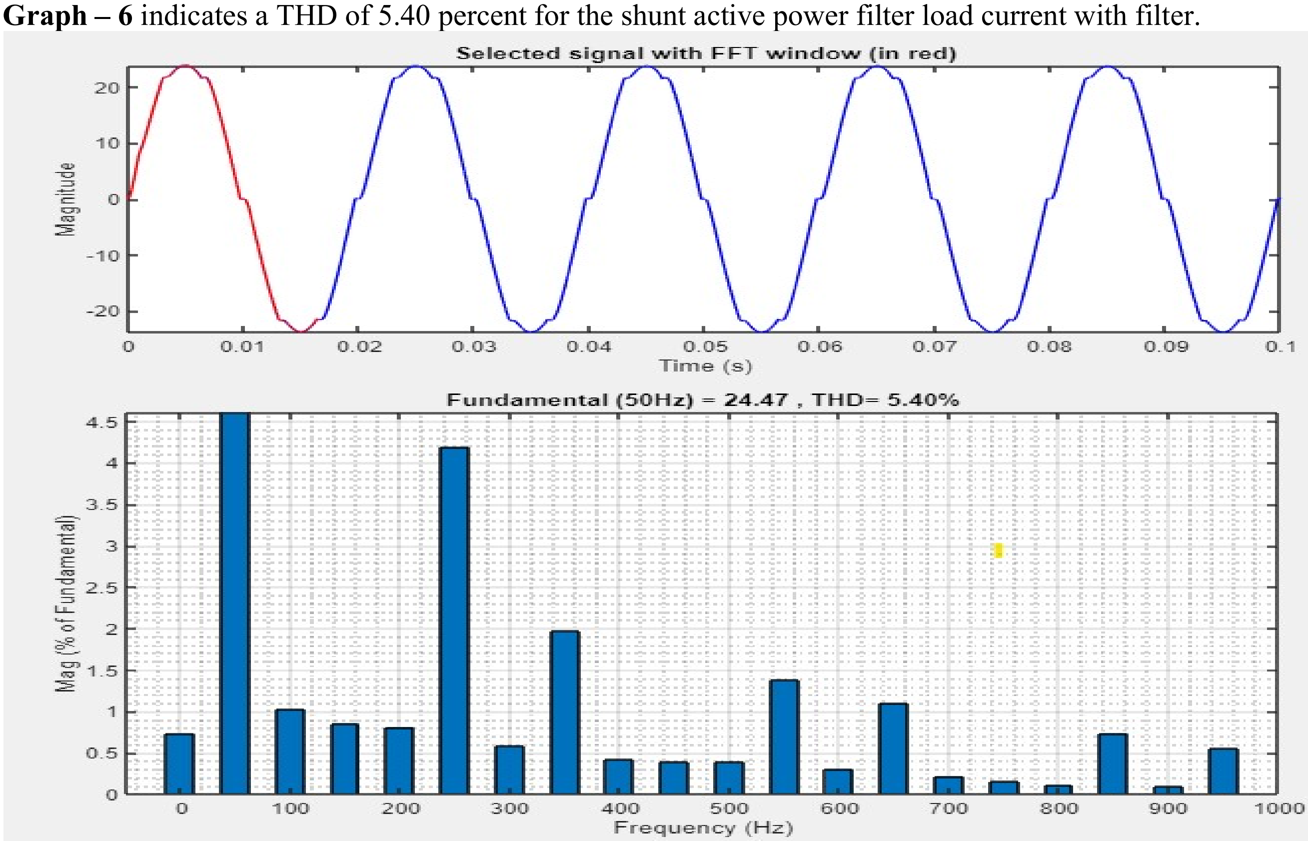
Non-linear load connected to the grid occurs anytime all systems are integrated into a micro grid; therefore, certain harmonics are present in the system. To address this issue, we employ Shunt APF to reduce the harmonics in the system, as seen in the THD analysis figures. APF Lower the THD value from 12% to 5.40 percent.[15]

Graph - 5 Displays Shunt THD Without a filter, the active power filter load current is 12.80%.



Graph – 5: THD of load current without filter

Graph – 6 indicates a THD of 5.40 percent for the shunt active power filter load current with filter.



Graph – 6: THD of load current with Shunt APF filter

VI. BIDIRECTIONAL CONVERTER WITH BATTERY SYSTEM

The battery is connected via a dc-dc bidirectional converter. The dc-dc converter uses IGBT due to its low output impedance and fast switching time. combining a non-traditional energy source—like a photovoltaic array—with a storage system, many operating modes, and a local load. Both the PV output and the battery's state of charge (SOC) affect these modes. The MATLAB Simulink model of a bidirectional converter with a battery system is displayed in **Figure - 7.**[16]

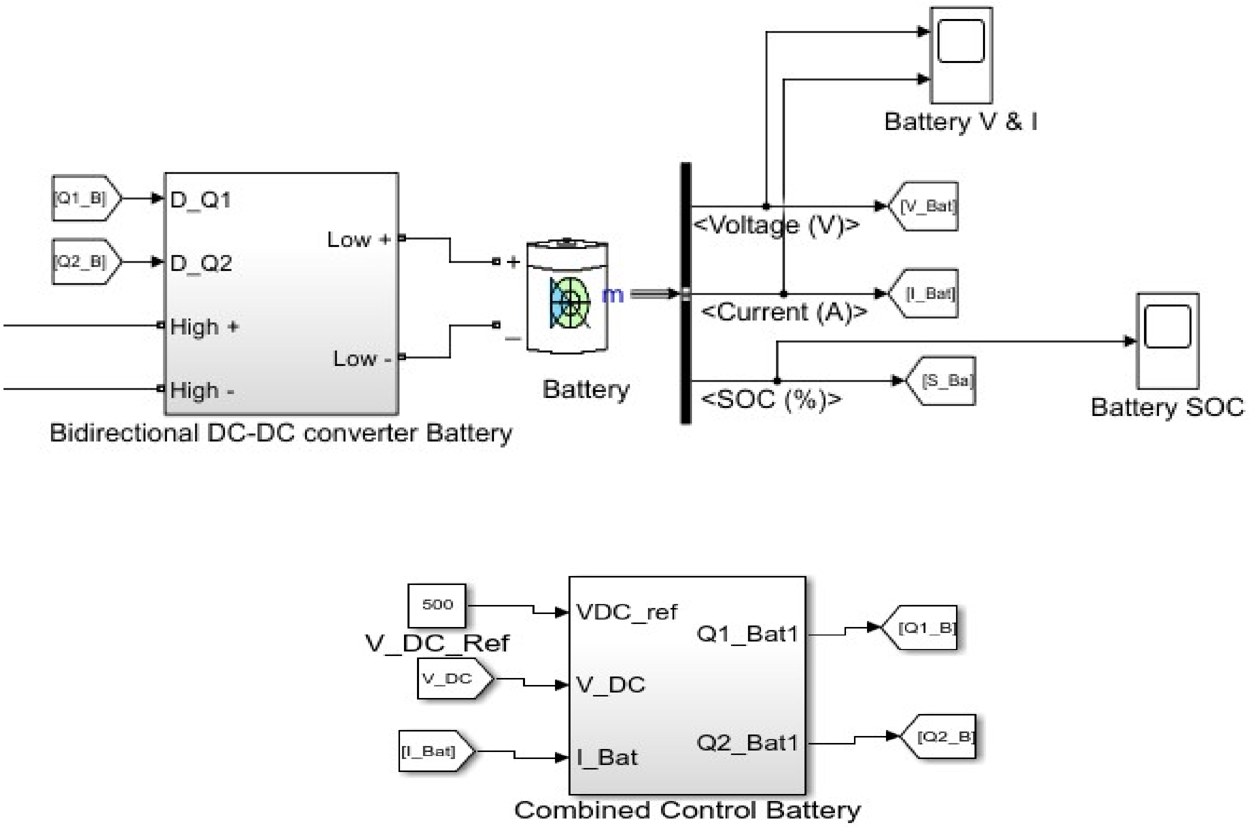


Figure – 7 MATLAB Simulink model of Bidirectional Converter with Battery system

Figure – 8 displays the bidirectional converter model in MATLAB Simulink.

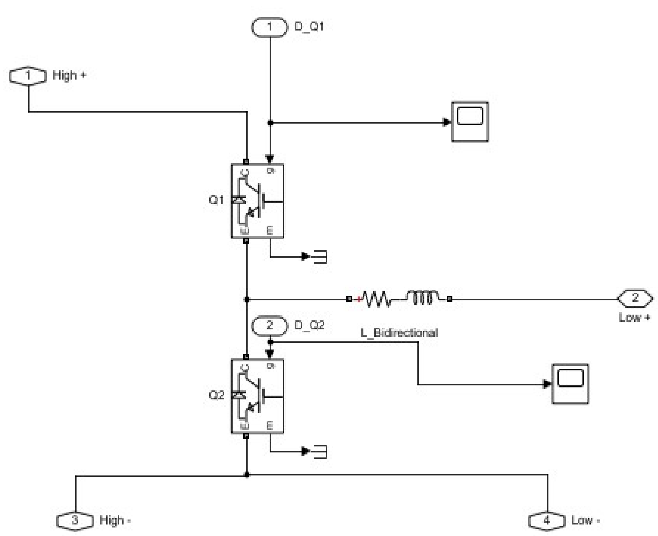
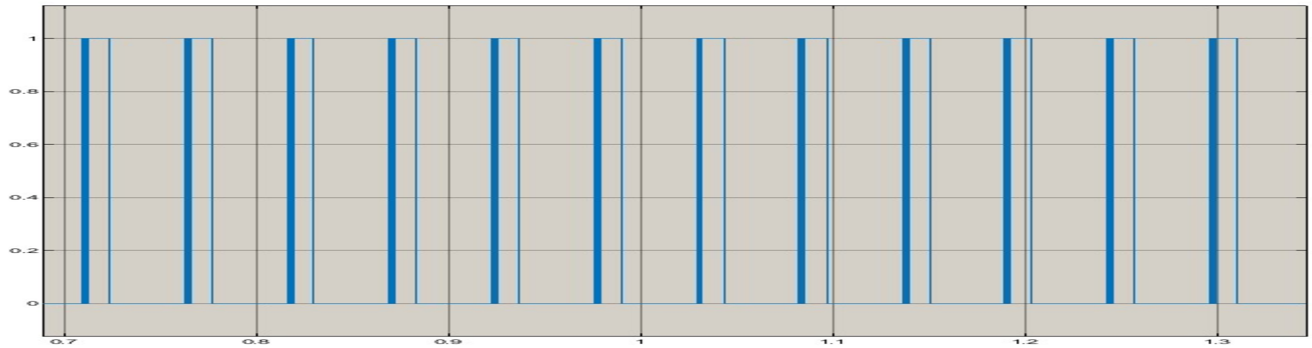


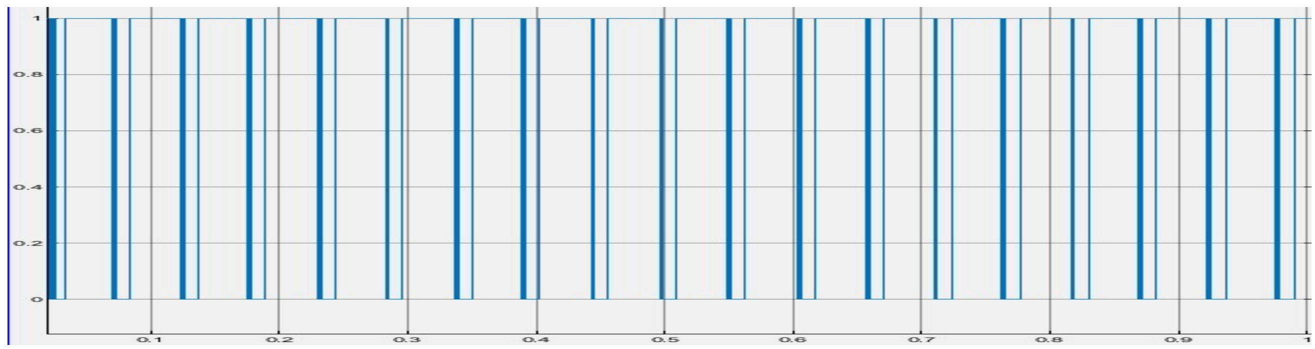
Figure – 8 MATLAB Simulink model of Bidirectional Converter

- It consists two IGBT Q1 & Q2
- Q1 Operate in Boost Mode
- Q2 Operate in Buck Mode
- Gate pulse of Q1 & Q2 Switches is providing by This Combined Control Battery System.

Graph – 7 displays the IGBT Q1's switching pulses.

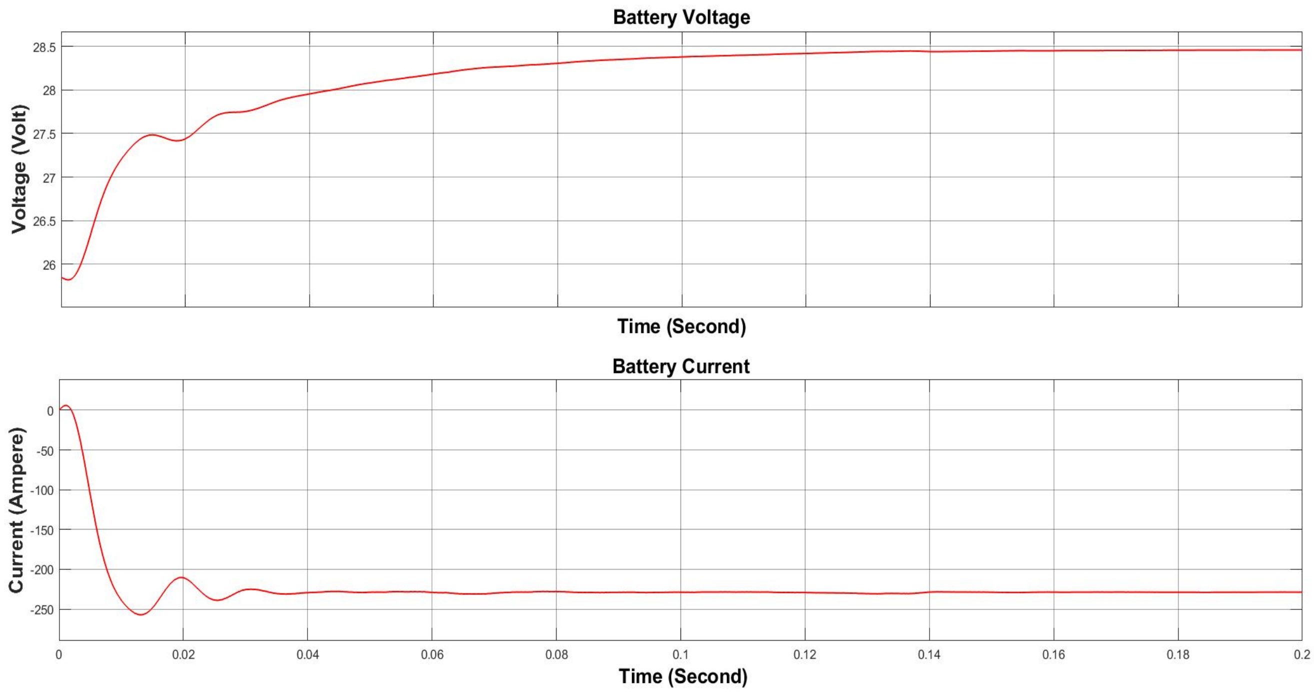


Graph – 8 displays IGBT Q2's switching pulses.



- **Battery Voltage and Battery Current Characteristics in Charging Mode:**

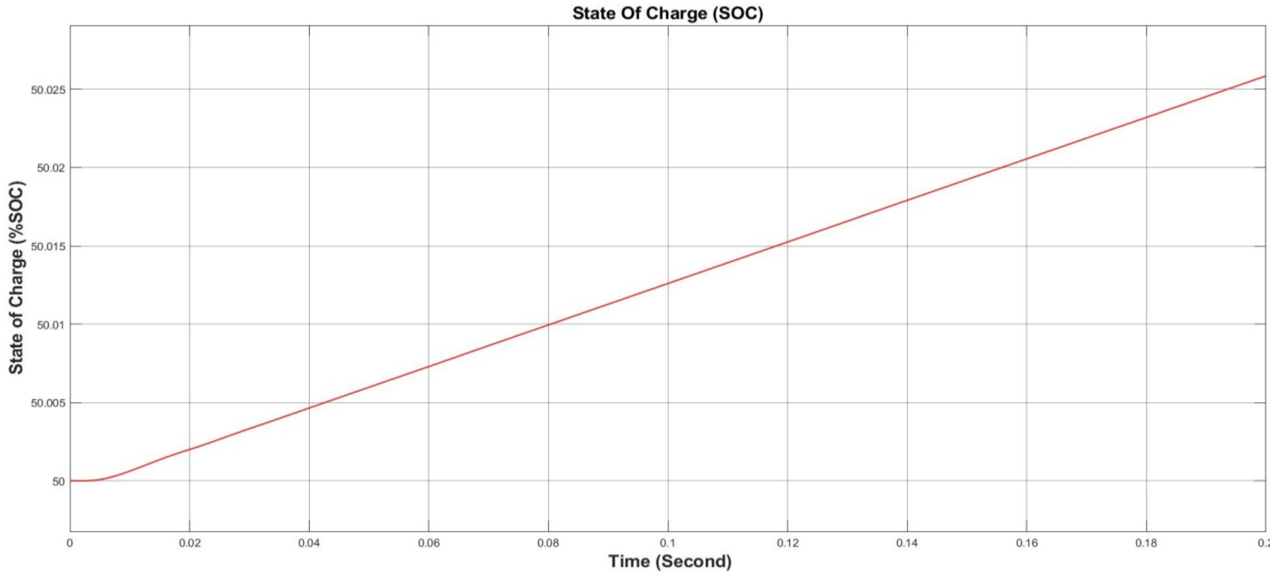
Graph – 9 displays the characteristics of the battery's voltage and current when charging.



Graph – 9: Voltage & Current Characteristics in Charging Mode

The output of a PV array can be stored in a battery for later use or transmitted into the grid. to make low-voltage energy storage possible. When the grid voltage is 400V and the battery voltage is 24V, the bidirectional converter is emulated in both boost and buck modes. It permits bidirectional power transfer from the grid to the batteries. 28.5 volts at that moment, both the voltage and the current (-250 A) are constant.[17]

Graph – 10 Shows Battery State of Charge (SOC) in %



Graph – 10: Battery SOC in %

VII. DATA COLLECTION AND RESULT SUMMARY

Table – 1 demonstrates data gathered by simulation, together with a summary of the results.

Sr. No.	DATA COLLECTED	RESULT SUMMARY
1	Output Voltage of Inverter	570 Volts
2	Output Current of Inverter	65 Amp.
3	THD of shunt Active power filter load current without filter	12.80 %
4	THD of shunt Active power filter load current without filter	5.40 %
5	Nominal Voltage	24 Volts
6	Rated Capacity of Battery	48 Ah
7	Initial state-of-charge of Battery in %	50 %
8	0s to 0.2s SOC % of Battery	50.025

Table – 1 Data Collection and Result Summary

VIII. CONCLUSION

- Through this study, I learnt how solar PV panels integrate with the grid to power electric vehicle charging systems.[18]
- To oversee the charging stations for a significant number of EVs, a more advanced energy management system is needed.[18]
- I gained the skills and knowledge necessary to construct an inverter that integrates the power output of solar PV panels with the utility grid.[19]
- Simulation results from MATLAB Simulink have validated the suggested system.[19]
- Simulation findings using MATLAB Simulink have confirmed the harmonic extraction and mitigation technique.[20]
- There are several potential limits to the findings, including a reduction in the electricity available at the charging station at night due to the grid operating in peak event mode and the BSB's limited stored energy.[20]

IX. DECLARATION

- Not Applicable and This Research Project is Self-funded.

X. CONFLICT OF INTEREST/DECLARATION OF COMPETING INTEREST

- On behalf of all the authors, the corresponding author states that there is no conflict of interest. This Research project is Self-funded.

XI. REFERENCES

[1] Z. Asimiyu, 'Renewable Energy and Electric Vehicles in Power Grids : Addressing Integration Challenges and Maximizing Benefits', no. October, 2024.

[2] G. Ramanathan, B. Chokkalingam, and J. L. Munda, 'PV-Assisted grid connected multi output electric vehicle charger with PV2V, G2V and PV2G functions', *PLoS One*, vol. 19, no. 6 June, pp. 1–22, 2024, doi: 10.1371/journal.pone.0304637.

[3] M. Irfan, S. Deilami, S. Huang, and B. P. Veettil, 'Rooftop Solar and Electric Vehicle Integration for Smart, Sustainable Homes: A Comprehensive Review', *Energies*, vol. 16, no. 21, 2023, doi: 10.3390/en16217248.

[4] S. Sheik Mohammed, F. Titus, S. B. Thanikanti, S. M. Sulaiman, S. Deb, and N. M. Kumar, 'Charge Scheduling Optimization of Plug-In Electric Vehicle in a PV Powered Grid-Connected Charging Station Based on Day-Ahead Solar Energy Forecasting in Australia', *Sustain.*, vol. 14, no. 6, 2022, doi: 10.3390/su14063498.

[5] M. M. Irfan, S. S. Rangarajan, E. R. Collins, and T. Senjyu, 'Enhancing the power quality of the grid interactive solar photovoltaic-electric vehicle system', *World Electr. Veh. J.*, vol. 12, no. 3, 2021, doi: 10.3390/wevj12030098.

[6] M. Shafiullah, S. D. Ahmed, and F. A. Al-Sulaiman, 'Grid Integration Challenges and Solution Strategies for Solar PV Systems: A Review', *IEEE Access*, vol. 10, no. January, pp. 52233–52257, 2022, doi: 10.1109/ACCESS.2022.3174555.

[7] A. Tavakoli, S. Saha, M. T. Arif, M. E. Haque, N. Mendis, and A. M. T. Oo, 'Impacts of grid integration of solar PV and electric vehicle on grid stability, power quality and energy economics: A review', *IET Energy Syst. Integr.*, vol. 2, no. 3, pp. 215–225, 2020, doi: 10.1049/iet-esi.2019.0047.

[8] A. S. Samosir and A. H. M. Yatim, 'Implementation of dynamic evolution control of bidirectional DC-DC converter for interfacing ultracapacitor energy storage to fuel-cell system', *IEEE Trans. Ind. Electron.*, vol. 57, no. 10, pp. 3468–3473, 2010, doi: 10.1109/TIE.2009.2039458.

[9] E. Rwamurangwa, J. D. Gonzalez, and A. Butare, 'Integration of EV in the Grid Management: The Grid Behavior in Case of Simultaneous EV Charging-Discharging with the PV Solar Energy Injection †', *Electricity*, vol. 3, no. 4, pp. 563–585, 2022, doi: 10.3390/electricity3040028.

[10] H. R. Iskandar, E. Taryana, A. Daelami, U. Jenderal, and A. Yani, 'Modelling of A Hybrid Photovoltaic-Grid Source on Public Electric Vehicle Charging Station (PEVCS)', *Join J. Soc. Sci.*, vol. 1, no. 5, pp. 144–154, 2024, [Online]. Available: https://ejournal.mellbaou.com

[11] S. Kumar, T. Upadhyay, and O. H. Gupta, 'Power Quality Improvement and Signal Conditioning of PV Array and Grid Interfaced Off-Board Charger for Electric Vehicles with V2G and G2V Capabilities', *Chinese J. Electr. Eng.*, vol. 9, no. 4, pp. 132–143, 2023, doi: 10.23919/CJEE.2023.000027.

[12] M. İnci, Ö. Çelik, A. Lashab, K. Ç. Bayındır, J. C. Vasquez, and J. M. Guerrero, 'Power System Integration of Electric Vehicles: A Review on Impacts and Contributions to the Smart Grid', *Appl. Sci.*, vol. 14, no. 6, pp. 1–24, 2024, doi: 10.3390/app14062246.

[13] M. Umair, N. M. Hidayat, A. Sukri Ahmad, N. H. Nik Ali, M. I. M. Mawardi, and E. Abdullah, 'A renewable approach to electric vehicle charging through solar energy storage', *PLoS One*, vol. 19, no. 2 February, pp. 1–14, 2024, doi: 10.1371/journal.pone.0297376.

[14] P. Rani, V. P. Arora, and N. K. Sharma, 'An overview of integration of PV system into electric grid', *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1228, no. 1, p. 12017, 2022, doi: 10.1088/1757-899x/1228/1/012017.

[15] T. Alviannanda and V. Lystianingrum, 'Business Model Innovation of Off Grid Public Electric Vehicles Battery Swap Station with Solar Powered', *E3S Web Conf.*, vol. 500, pp. 1–10, 2024, doi: 10.1051/e3sconf/202450003028.

[16] A. Dukpa, B. Butrylo, and B. Venkatesh, 'Comparative Analysis and Optimal Operation of an On-Grid and Off-Grid Solar Photovoltaic-Based Electric Vehicle Charging Station', *Energies*, vol. 16, no. 24, pp. 1–17, 2023, doi: 10.3390/en16248086.

[17] T. G. Tareen, M. Aamir, J. Khan, G. Husnain, and F. Anjam, 'Design of a Multi-Mode Power Management System for Electric Vehicles with Grid Integration', vol. 20, no. 3, 2024.

[18] B. B. AKHILESH, A. DANIEL, S. DIVYASHREE, M. S. HIMASHREE, and D. K. MANU, 'Design and Implementation of Solar Grass Cutter', *i-manager's J. Electr. Eng.*, vol. 14, no. 4, p. 47, 2021, doi: 10.26634/jee.14.4.18368.

[19] M. Al Imran Fahim and M. S. Uddin Yusuf, 'Energy Management System of a PV-Based Grid-Connected Electric Vehicle in Bangladesh', *2023 10th IEEE Int. Conf. Power Syst. ICPS 2023*, no. December 2023, pp. 1–6, 2023, doi: 10.1109/ICPS60393.2023.10429012.

[20] R. A. Khan, N. Islam, S. Ahmad, B. Sabir, M. A. Husain, and H. Liu, 'Advances in Solar PV-Powered Electric Vehicle Charging System', *Photovolt. Syst. Technol.*, pp. 63–83, 2024, doi: 10.1002/9781394167678.ch4.

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