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Solar-Powered Grid-Integrated Electric Vehicle Charging with Bidirectional Energy Flow System

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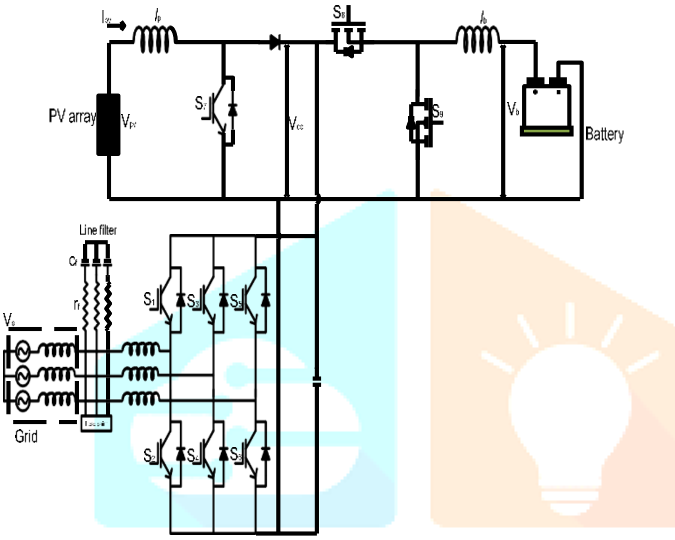
Abstract - This research proposes a comprehensive three-phase grid integration system incorporating solar energy through a bidirectional buck-boost converter topology. The photovoltaic (PV) array output undergoes a boosting process via the bidirectional DC-DC converter, with control facilitated by the Maximum Power Point Tracking (MPPT) technique for optimal power extraction. The grid and PV array operate in parallel, ensuring a continuous power supply to electric vehicle (EV) batteries. The study advocates for utilizing EV batteries as energy storage units in microgrids, employing Grid-To-Vehicle (G2V) and Vehicle-To-Grid (V2G) strategies to manage energy surplus and deficit. The paper underscores the importance of establishing infrastructure and control mechanisms for effective implementation. The research delineates the architecture of EV battery charging within a V2G-G2V system on a microgrid, demonstrating power transfer through simulation. Test results reveal that EV batteries actively regulate microgrid power dynamics using G2V-V2G operating modes. The proposed controller exhibits enhanced dynamic performance in terms of DC bus voltage stability, and the charging station design mitigates harmonic distortion in grid-injected current.

Keywords – Optimal charging scheduling, vehicle to grid, grid to the vehicle, bidirectional dc-dc converter, MPPT technique, Solar plugin hybrid electric vehicle, Batteries, Charge controller, HEV, Bi-directional DC convertor), DC Grids, Digital charging test bed, Plug-in electric vehicle, Photo voltaic cell control, Smart grid, Magnetic resonance, Power system of vehicle, Fuel cell vehicle, Internal combustion engine vehicle.

I. Introduction

Power quality is a critical aspect of power systems, encompassing issues such as power factor reduction, insulation failure, line losses, and communication interference. Custom power devices (CPDs) play a crucial role in addressing these challenges by employing control techniques [1, 4]. The introduction of non-linear loads, as well as renewable energy sources with intermittent power, further complicates power quality, impacting voltage and current waveforms [2]. Device failures, such as capacitor and insulator failures, are observable manifestations of power quality issues. Shunt and series CPDs, like DSTATCOM, help compensate for disturbances in the power system, addressing unbalanced current, power factor correction, and voltage disturbances [3, 4]. Electrical engineers are actively engaged in designing effective control algorithms considering these issues and advancements in DSTATCOM topologies [6, 8]. Numerous control methods have been developed to enhance the effectiveness of DSTATCOM under various voltage circumstances, including balanced, sinusoidal, unbalanced, or distorted AC voltages. Adaptive control techniques, such as those mentioned [12, 14, 16, 15, 17, 19], contribute to improved performance in diverse loading conditions, including non-linear and electric vehicle (EV) loads. In the context of power controllers, voltage and frequency control are paramount. Frequency control is achieved through Phase Locked Loop (PLL), while voltage control utilizes voltage regulation controllers often employing Proportional-Integral (PI) controllers in the voltage and current control loops. The PLL generates reference sin and cos components in phase with the Point of Common Coupling (PCC) voltages .The i-cos approach, commonly used, has limitations, especially in addressing customization issues. The DQ-based control technique overcomes these drawbacks, regulating the voltage at the PCC using a PI controller and controlling the voltage across the DC bus capacitor by developing the reference for the direct axis component in the voltage regulation controller. The study evaluates the performance of the i-cos approach under various loading conditions, including non-linear and EV loads, and compares results when substituting the PI controller with a fuzzy controller. Addressing power quality issues requires a nuanced approach involving custom power devices, advanced control techniques, and continuous adaptation to evolving power system dynamics. The comparison of control methods, such as PI controllers and fuzzy controllers, adds to the understanding of optimizing power system performance.

II. CIRCUIT DESCRIPTION



This section describes the circuit design and control strategies for a suggested power electronics converter module. The diagram in Figure 1 illustrates the architecture of a grid-integrated photovoltaic (PV) system with electric vehicle (EV) charging. The key feature is the integration of the PV array with the grid, using a buck-boost topology for bidirectional power flow. This design enhances system stability. In simpler terms, it shows how solar power and the electric grid work together using a special circuit to efficiently charge electric vehicles in both directions.

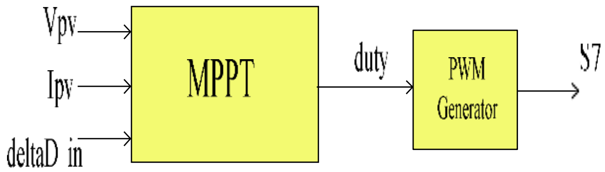
A. Solar PV-fed EV battery

B. Grid-fed EV battery

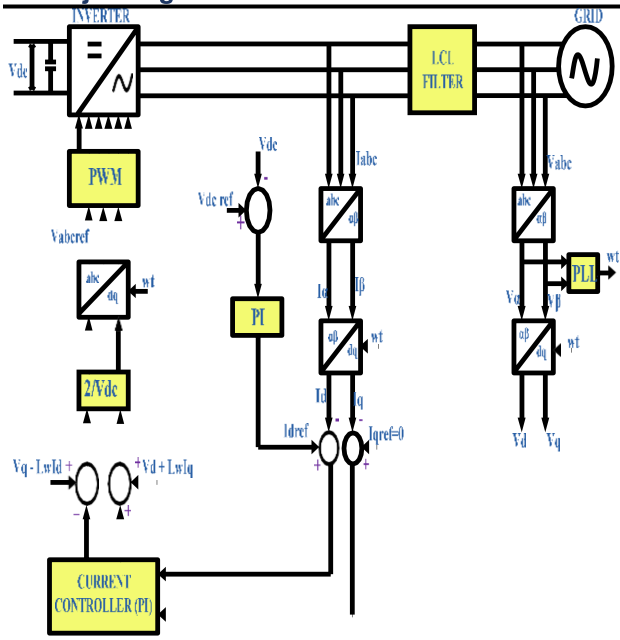
In the context of electrical systems, where power and signals traverse various lines, the persistent challenge lies in mitigating undesirable phenomena such as radio frequency interference (RFI) and electromagnetic interference (EMI). Addressing these issues is critical for ensuring the integrity of power and signal transmission. The initial line of defense involves the incorporation of a front-end bridge rectifier. This rectifier serves the purpose of rectifying incoming electrical signals, optimizing them for subsequent utilization in charging and discharging battery systems.

Elevating the sophistication further, an active front end (AFE) is introduced, offering multifaceted advantages beyond harmonic reduction and presenting potential cost efficiencies for end users. Unlike conventional rectifiers employing diodes, an AFE leverages insulated gate bipolar transistors (IGBTs) to effectuate the conversion of alternating current (AC) to direct current (DC). The appellation "active" stems from the dynamic nature of IGBTs, acting as electronic switches under precise control. One of the notable benefits of an AFE is its capability to curtail total harmonic distortion (THD) to a level below 5 percent. THD serves as a metric quantifying the deviation of electrical waveforms from ideal sinusoidal patterns. The AFE achieves this by continuously analyzing the incoming current waveform and meticulously shaping it to conform to sinusoidal characteristics. It is imperative to underscore that THD measurement predominantly considers lower-order harmonics, necessitating additional measures to attenuate higher-order harmonics stemming from the switching frequency of IGBTs. To this end, the incorporation of an LCL filter becomes indispensable, functioning as a requisite component for diminishing unwanted disturbances and refining the quality of the electrical signals.

III. CONTROL TECHNIQUE

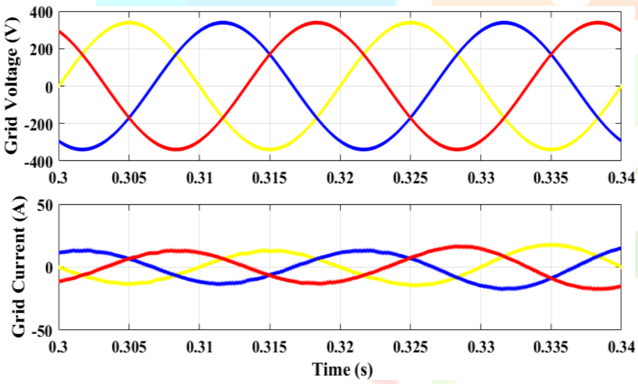


This investigation encompasses a triad of control methodologies. Firstly, the Maximum Power Point Tracking (MPPT) technique is employed for regulating the output of the photovoltaic (PV) system. MPPT serves as an algorithmic mechanism within PV inverters, dynamically adjusting the impedance faced by the solar array to optimize the PV system's performance near the peak power point under diverse conditions, including variable solar irradiation, load changes, and temperature fluctuations. For a more intricate breakdown, the MPPT control technique is graphically depicted in Fig. 2, showcasing its application to the PV array. Moving to the second control mechanism, it pertains to governing the charging and discharging modes of the buck-boost converter. Specifically, during the buck mode (charging), the upper switch S8 is activated, reducing the input voltage Vdc to match the charging voltage. Conversely, in boost mode (discharging), the operation involves the activation of switch S9, augmenting the battery voltage to the DC bus voltage. The third facet involves the nuanced management of the active (id) and reactive (iq) components of the three-phase input current during the rectifier control process in the dq-frame. This intricate control process ensures precise handling of the electrical input in both its active and reactive dimensions. Furthermore, an additional layer of complexity is introduced with the implementation of a constant current control technique, where Proportional-Integral (PI) controllers are deployed for orchestrating the charge and discharge operations within the battery charger circuit. The decision-making process involves a comparator that scrutinizes the reference battery current against zero to discern the current signal's polarity. Following the determination of the mode (charge or discharge), a PI controller compares the reference current with the measured current, generating switching pulses for switches S8 and S9 based on the resultant difference. In essence, the study delves into a sophisticated realm of control strategies encompassing MPPT algorithms, charge/discharge mode management for the buck-boost converter, and intricacies associated with three-phase input current control in the dq-frame, all augmented by the implementation of constant current control techniques involving PI controllers.



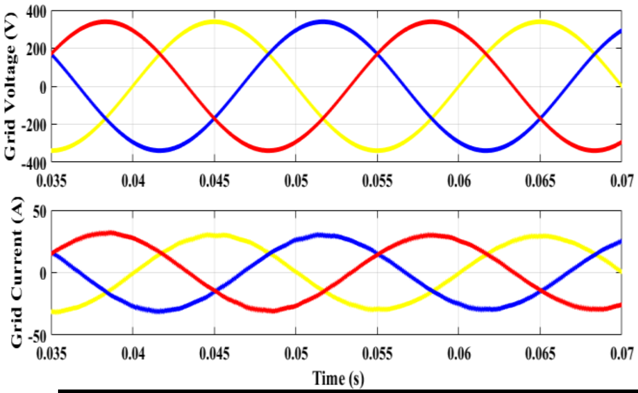
IV. SIMULATION RESULTS AND DISCUSSION

The envisaged operational methodology articulated in this paper entails the concurrent parallel connection of two distinct power sources, namely solar energy and the grid. This parallel arrangement is orchestrated to furnish power to an electric vehicle through the application of the envisaged buck-boost converter topology. This converter topology is designed to facilitate bidirectional power flow, accommodating both charging and discharging modes seamlessly. In instances

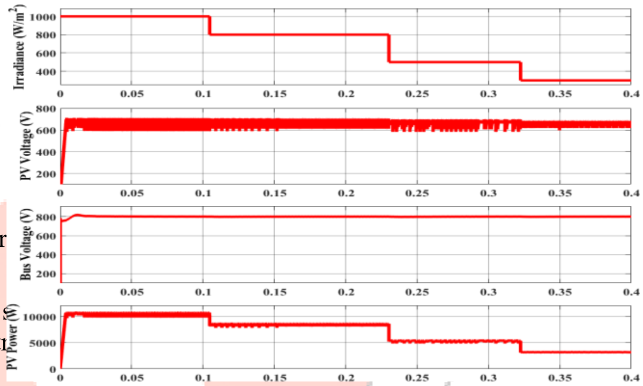


where solar energy is not forthcoming or accessible, the sole operational source becomes the grid. This contingency situation mandates a seamless transition to a scenario where the entire power supply for the electric vehicle battery is sourced exclusively from the grid. This meticulous design ensures an uninterrupted and continuous power supply to the electric vehicle battery under circumstances where solar energy is either insufficient or unavailable.

A. PV array



The simulation outcomes pertaining to the Photovoltaic (PV) array are visually represented in Figure 5. In response to distinct irradiation levels, the PV output voltage, output current, and PV output power exhibit fluctuations commensurate with the varying irradiation conditions. However, a notable contrast is observed in the boosted output of the PV system, specifically in the form of bus voltage, which remains steadfast and unwavering. This constancy is attributed to the meticulous implementation of the Maximum Power Point Tracking (MPPT) technique. In more intricate terms, while the individual components of PV performance, such as voltage, current, and power, demonstrate sensitivity to irradiation changes, the bus voltage, representing the consolidated output, remains impervious to these fluctuations due to the effective MPPT implementation. The MPPT technique acts as a stabilizing force, ensuring that despite variations in irradiation levels, the overall boosted output of the PV system, represented by bus voltage, maintains a consistent and optimized state.



B. Gr

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B.Grid

The simulation outcomes related to the grid dynamics are illustrated in Figure 6. This depiction encompasses Three-phase voltage and current waveforms. In the discharging mode, a distinctive phase relationship of 180 degrees between voltage and current emerges. This signifies that the power dynamics involve an injection of power into the grid. Conversely, during the charging mode, an observable alteration in the phase relationship occurs, aligning the voltage and current
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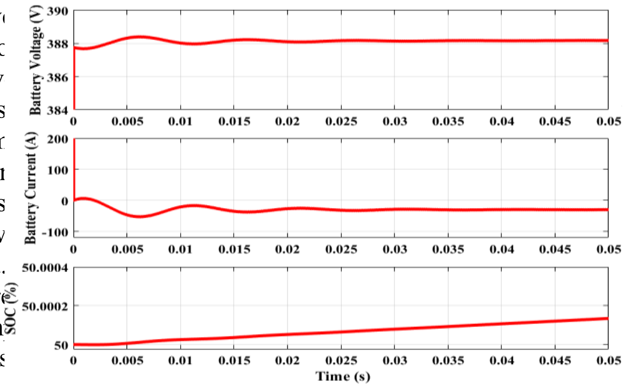


Fig. 6. Grid voltage and current during discharging mode (a) and charging mode (b).

C. Battery parameter

The battery parameters, encompassing state of charge (SOC), current, and voltage, are graphically presented in Figure 7. Notably, during the charging phase, the current assumes a negative value, indicative of the energy influx into the battery. Conversely, in the discharging phase, the current adopts a positive value, signifying the release of stored energy. The battery voltage is specified at 388V, and the current registers at 30 A, resulting in a state of charge of 50%. Figure 8 and Table I collectively encapsulate the power dynamics for solar PV, grid active power, and battery power across distinct operational modes.

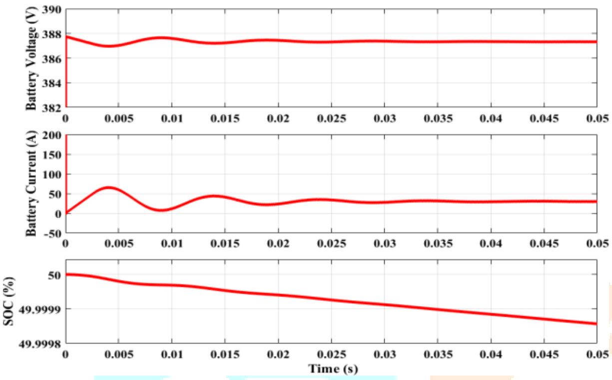
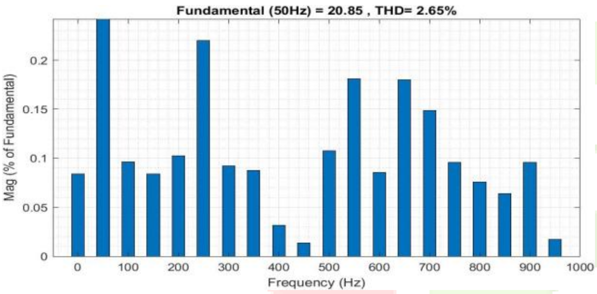


Fig. 7. SOC, current, and voltage of the battery during charging mode (a) and discharging mode (b).

In Mode 1, the grid is the primary contributor, supplying



power to the electric vehicle (EV) battery in a Grid-to-Vehicle (G2V) operational configuration. In Mode 2, the EV battery transforms into a power source, delivering energy to fulfill the grid's load demand in a Vehicle-to-Grid (V2G) scenario. Mode 3 introduces a scenario where both the PV array and the grid collaboratively provide power to the EV battery. Mode 4 revolves around the battery functioning as an energy storage system, with both the PV array and the battery contributing power to cater to the grid's load demand. In Mode 5, both the PV array and the EV battery simultaneously feed power into the grid. Mode 6 showcases a distinct setup, featuring a PV-based EV charger isolated from the grid, supplying power to both the EV battery and the grid, while the grid remains isolated. In essence, these diverse operational modes demonstrate the versatility and bidirectional power flow capabilities of the system, catering to a spectrum of scenarios ranging from grid-dependent to grid-independent configurations with active involvement of the PV array, the EV battery, and the grid.

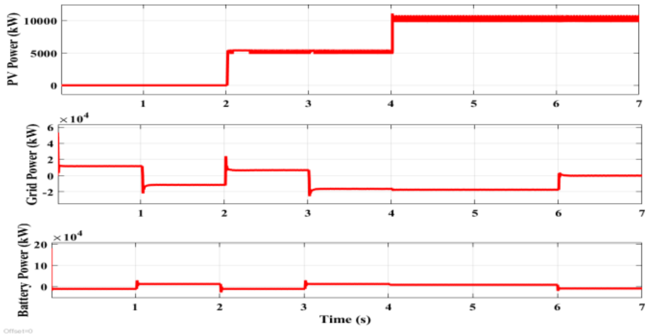


Fig. 8. Power for solar PV, grid active power and battery power for different modes of operation.

TABLE I. OUTPUT POWER OF PV ARRAY, BATTERY, AND GRID

Modes of Operation	Irradiance (W/m2)	PV Power (kW)	Battery Power (kW)	Grid Power (kW)
1	0	0	-11	11
2	0	0	11	-11
3	500	5	-11	6
4	500	5	11	-16
5	1000	10	7	-17
6	1000	10	10	0

D. THD Calculations

Fig.9. THD of Grid Current.

The Total Harmonic Distortion (THD) of the grid current, as depicted in Figure 9, lies within the acceptable range, specifically at 2.65%. This implies that the harmonic content in the grid current is at a level considered normal and poses no significant deviation from the desired sinusoidal waveform. Therefore, it is deemed safe to reintroduce the energy back into the grid, affirming that such an injection of power will not exert any adverse impact on the overall performance and stability of the grid. In more intricate terms, the THD metric provides a quantitative measure of the extent to which the grid current deviates from an ideal sinusoidal waveform. The recorded THD value of 2.65% falls within a predefined range deemed acceptable for grid operations. Consequently, the conclusion is drawn that the harmonics present in the grid current are sufficiently low to ensure the safe and seamless integration of the system's energy back into the grid without causing detrimental effects on the grid's performance characteristics.

V. CONCLUSION

The proposed grid-integrated PV array system with bidirectional power flow, connected to an EV battery, presents a versatile solution for diverse scenarios, including varying solar irradiances, continuous power supply needs, and situations where the grid is unreachable. The incorporation of a buck-boost converter topology in the EV battery allows for efficient charging and discharging operations based on demand. The system's capability to maintain continuous power supply is realized through the parallel connection of different sources, ensuring resilience and adaptability. Furthermore, the system's adherence to low Total Harmonic Distortion (THD) levels contributes to an improved power quality when integrating with the grid. Looking forward, future developments could explore the integration of additional battery energy sources and multiple input multiple output (MIMO) systems. This strategic evolution is poised to enhance reliability and ensure a consistent power supply, thereby fortifying the overall performance and robustness of the grid-integrated PV array system with bidirectional power flow.

References

[1] Mishra, D., Singh, B., & Panigrahi, B. K. (2022). Sigma-Modified Power Control and Parametric Adaptation in a Grid-Integrated PV for EV Charging Architecture. IEEE Transactions on Energy Conversion,
37(3), 1965–1976.
https://doi.org/10.1109/TEC.2022.3145884

[2] Kurinjimalar, L., Chandhrasekaran, G., Jeevanandham, S., Prathish Kumar, U., Hemalatha, M., & Ranjith, M. (2022). Analysis of Vehicle to Grid (V2G) Integration in Renewable based Micro grid. 3rd International Conference on Power, Energy, Control and
Transmission Systems, ICPECTS 2022 - Proceedings.
https://doi.org/10.1109/ICPECTS56089.2022.10047328

[3] Ji, C., Liu, Y., Lyu, L., Li, X., Liu, C., Peng, Y., & Xiang, Y. (2020). A Personalized Fast-Charging Navigation Strategy Based on Mutual Effect of Dynamic Queuing. IEEE Transactions on Industry Applications,
56(5), 5729–5740.
https://doi.org/10.1109/TIA.2020.2985641

[4] Mallik, A., Lu, J., & Khaligh, A. (n.d.). Sliding Mode Control of Single Phase Interleaved Totem-Pole PFC for Electric Vehicle Onboard Chargers. https://doi.org/10.1109/TVT.2018.288238

[5] Pandey, R., & Singh, B. (2020). Canonical Switching Cell (CSC) Converter-Based Power Factor-Corrected Battery Charger for E
Rickshaw. IEEE Transactions on Industry Applications, 56(5), 5046–5055.

[6] Mohammed Shakeel, F., Malik, O. P., & Ieee, L. (2019). Vehicle-To-Grid Technology in a Micro-grid Using DC Fast Charging Architecture. In 2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE).

[7] K. M. Tan, V. K. Ramachandaramurthy, and J. Y. Yong, “Bidirectional battery charger for electric vehicle,” in 2014 IEEE Innovative Smart Grid Technologies – Asia, ISGT ASIA 2014, 2014,
pp. 406-411.

[8] Gupta, M., Seth, A. K., & Singh, M. (2022). Grid Tied Photovoltaic Based Electric Vehicle Charging Infrastructure. 2022 2nd International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies, ICAECT 2022.
https://doi.org/10.1109/ICAECT54875.2022.9808038

[9] Singh, V., Kaur, L., Kumar, J., & Singh, A. (2022). Solar PV Tied Electric Vehicle Charging System Using Bidirectional DC-DC Converter. ICPC2T 2022 - 2nd International Conference on Power, Control and Computing Technologies, Proceedings.
https://doi.org/10.1109/ICPC2T53885.2022.9776973

[10] Kumar, N., & Soni, R. K. (2022). Modelling and Simulation of Charging Based on Solar/Grid Powered Electric Vehicle. Proceedings of International Conference on Computational Intelligence and
Sustainable Engineering Solution, CISES 2022, 605–610.
https://doi.org/10.1109/CISES54857.2022.9844405

[11]Jain, V., Singh, B., & Seema. (2023). A Grid Connected PV Array and Battery Energy Storage Interfaced EV Charging Station. IEEE Transactions on Transportation Electrification, 1–1.
https://doi.org/10.1109/tte.2023.3234994.

[12] Shubhra, & Singh, B. (2020). Control of Three-Phase Grid Integrated Multiple Solar Photovoltaic Arrays-BES Based Microgrid. 2020 IEEE 5th International Conference on Computing Communication and Automation, ICCCA 2020, 120–125.
https://doi.org/10.1109/ICCCA49541.2020.9250924

[13] Singh, B., Verma, A., Chandra, A., & Al-Haddad, K. (2020). Implementation of Solar PV-Battery and Diesel Generator Based Electric Vehicle Charging Station. IEEE Transactions on Industry Applications,
56(4), 4007–4016.
https://doi.org/10.1109/TIA.2020.2989680

[14] R. Mandloi, J. Rajender and M. Dubey, "Grid Integrated Electrical Vehicle Bi-Directional Charging Station," 2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS), Bhopal, India, 2023, pp. 1-5, doi:
10.1109/SCEECS57921.2023.10063043.

[15] Abuelrub, A., Hamed, F., Hedel, J., & Al-Masri, H. M. K. (2023). Feasibility Study for Electric Vehicle Usage in a Microgrid Integrated with Renewable Energy. IEEE Transactions on Transportation Electrification. https://doi.org/10.1109/TTE.2023.3243237

[16] Bhattacharya, S., & Samanta, S. (2019, December 1). Modified incremental conductance MPPT algorithm for very fast changing atmospheric condition for solar electric vehicle application. 2019 IEEE 16th India Council International Conference, INDICON 2019 –
Symposium

[17] R. Jatoth and M. Dubey, "High Voltage Trigger Generator for Magnetic Pulse Welding System," 2022 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS), 2022, pp. 1-4, doi: 10.1109/SCEECS54111.2022.9740759.