

Grid-Connected Solar PV Systems and Power Quality Review

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Chapter 2

Literature review

2.1 Introduction

The escalating demand for sustainable energy has driven the integration of solar PV systems into power grids. The employment of solar PV technology possesses enormous potential in lessening greenhouse gas emissions and ensuring a dependable energy source for the long term. PV materials and devices transform sunlight into electricity. A PV cell is a single device. A single cell usually generates 1 or 2 watts of power. These cells are made from various semiconductors and are very thin. To endure outdoor conditions for many years, cells are enclosed in protective layers of glass and/or plastics. PV cells are connected in chains to form larger units called modules or panels. Modules can be used individually or connected to form arrays. Arrays are connected to the electrical grid as part of a complete PV system. PV systems can be built for any power need. PV modules and arrays are a component of a PV system. Mounting structures and components convert DC electricity to AC electricity for home appliances. A [grid-connected PV system](#) is a system in which panels or arrays are connected to the utility grid through a power inverter unit allowing them to operate in parallel with the electric utility grid.

The investigation article primarily underscores solar photovoltaic (PV) systems that are connected to the grid. It analyzes diverse aspects of these systems, such as their design, control techniques, and configurations. Additionally, it looks at how AI techniques affect the entire PV system value chain, including design, forecast, control, and maintenance. Moreover, the article investigates the economic perks of integrating the PV system with the national grid, comparing it to the current system in place. The article offers a MATLAB Simulink model that may be utilized whether the system is connected to either the local low voltage grid or the national high voltage grid in order to simulate the system's functioning. In addition, the article carries out an examination on the reliability, availability, and maintainability (RAM) performance in practical grid-connected solar PV systems and exhibits a creative way to deal with streamline upkeep costs. It also evaluates the potential utilization of large-scale solar PV systems to improve the voltage stability of weak national grids. Furthermore, the article scrutinizes the operation and regulation of intelligent inverters used in solar and solar-plus-storage systems, with a particular focus on Volt-VAR Control. Finally, the article investigates the distribution of current harmonics and their correlation with power level in inverters and substations.

2.1.1 Grid connected solar PV systems

In 2017, Kumar *et al.* [1] examined the Solar photovoltaic (PV) systems that are linked to the grid. The setup of the PV array, maximum power point tracking (MPPT) techniques, direct current-direct current (DC-DC) converters, inverters, and control algorithms are all included in the grid-connected photovoltaic system's overall design. Various control techniques and configurations, along with their advantages and disadvantages, for grid-connected systems are meticulously examined. The comparisons between different conventional and advanced control techniques substantiate the feasibility of this architectural design. Diverse configurations and control methodologies of grid-connected PV systems are exhaustively scrutinized to validate the potential of grid-connected PV systems.

In 2021, Kurukuru *et al.* [2] analyzed the consequences of AI techniques on the PV value chain. The examination entails the mapping of the presently accessible AI technologies, the identification of potential future applications of AI, and the measurement of their benefits and drawbacks compared to traditional mechanisms. The existing approaches currently utilized for various functions within the solar PV industry, such as design, forecasting, control, and maintenance, have been discovered to yield relatively imprecise outcomes.

In 2017, AbdelHady [3] The objective of such modeling endeavor is to offer early assessment of the performance of the system. The financial savings of both scenarios are compared on the basis of the novel invoicing system. Findings reveal that the existing system conserves 100 thousand L.E./year, whereas connecting the system to the national grid will result in a savings of 235.8 thousand L.E./year. In this research paper, a MATLAB Simulink model is developed to simulate a detailed representation of the system, whether it is connected to the local low voltage grid or the national high voltage grid.

In 2019, Sayed *et al.* [4] estimated the RAM performance of practical grid-connected solar PV systems, an enhanced Reliability Block Diagram is introduced. The analysis initiates at the sub-assembly level and advances to the subsystem level, ultimately encompassing the overall system. To estimate the RAM performance of practical grid-connected solar PV systems, an enhanced Reliability Block Diagram is introduced. The input data necessary for this analysis are obtained from worldwide databases that record failures and repairs of various subassemblies under different meteorological conditions. Furthermore, a novel approach is suggested to determine the probability density function that most accurately fits each sub-assembly. By monitoring the critical subassemblies of a PV system, it becomes possible not only to enhance system availability but also to optimize maintenance costs.

In 2021, Adetokun *et al.* [5] evaluated the utilization of large-scale solar photovoltaic (SPV) systems for enhancing the voltage stability of weak national grids. The integration of large-scale SPV systems has been explored in the context of the Nigerian power system. Two scenarios involving an increase in SPV penetration level (PL) are studied in this investigation, namely, the implementation of centralized large-scale SPV at the critical bus, and the deployment of dispersed large-scale SPV across the weak buses. The findings demonstrate that with centralized SPV generation in the case study system, the highest bus voltage can be maintained within acceptable limits at a level of 26.29%

(1000 MW), while dispersed SPV achieves this at a level of 21.44% (800 MW).

In 2017, Mahela and Shaik [6] analysed a complete outline of grid-connected solar photovoltaic (PV) systems. The objective of this evaluation is to present a comprehensive view of the structure of grid-connected solar PV systems and their constituent elements, including solar cells, PV arrays, maximum power point tracking, filters, DC-DC converters, single-phase inverters, and three-phase inverters, to researchers, designers, and engineers involved in solar energy and its integration into the utility grid. A concise summary of the control methodologies for the single and three-phase inverters has also been included. Over 100 research publications on the topologies, configurations, and control methodologies of grid-connected solar PV systems and their primary constituent elements have been comprehensively examined and categorized for expeditious referencing.

In 2021, Kefale *et al.* [7] To ensure optimal distribution network parameters, an optimization tool must be utilized to determine the appropriate sizing and placement of the solar photovoltaic system within the Ethiopian radial distribution system. However, to fulfill the electricity demand of the nation and urban area, an alternative method is required rather than solely depending on the national power grid. The implementation of a solar photovoltaic system interconnection in radial feeders could provide a solution to power interruptions and improve overall network performance. To ensure optimal distribution network parameters, an optimization tool must be employed to determine the appropriate sizing and placement of the solar photovoltaic system within the Ethiopian radial distribution system. The key aims of this investigation are to reduce power loss and optimize the voltage profile of the radial distribution network. By utilizing selective particle swarm optimization (SPSO), the size and location of the solar power installation can be fixed to enhance network capacity. A multiobjective optimization problem is formulated to address various constraints that can be optimized by the SPSO algorithm. Ultimately, the application of SPSO facilitates the identification of the optimal size and site for solar power installation, leading to improved performance within the radial distribution network of Ethiopia. Table 2.1 shows the reviews by various authors about the Grid connected solar PV systems.

Table 2.1: Reviews of Grid connected solar PV systems

Authors	Aim	Advantages	Disadvantages
Kumar <i>et al.</i> 2017,	To provide the complete analysis of grid tied solar PV systems.	Grid-tied PV systems are considered a viable solution for supporting heavily loaded grids, thanks to advancements in power electronics technologies and the availability of solar light.	less current in series and less voltage in parallel.

Kurukuru <i>et al.</i> 2021,	To look into how AI methods affect the PV value chain.	The potential to facilitate the effective representation of the system, enhance power prediction, and administer and uphold the system's operation and upkeep.	Evolutionary algorithms, can be relatively complex.
AbdelHady 2017,	To provide an early evaluation of the performance of a micro grid-connected solar PV system tied either to the local low voltage grid or to the national high voltage grid.	The system can lead to large cost reductions. In the NWRC pilot rooftop PV system, connecting the system to the national grid was discovered to save 235.8 thousand L.E./year.	The system's result is influenced by the presence of sunlight, which can differ depending on weather conditions and geographical location.
Sayed <i>et al.</i> 2019,	To demonstrate a RAM analysis of grid-connected solar PV systems.	Monitoring subassemblies is important for improving system availability and reducing maintenance costs.	None mentioned
Adetokun <i>et al.</i> 2021,	To investigate the application of large-scale solar photovoltaic (SPV) systems for voltage stability improvement in weak national grids,	Large-scale SPV systems have benefits over shunt reactors, such as improved voltage stability and meeting energy demand.	Cost, Grid Integration, Maintenance and Variability
Mahela and Shaik 2017,	To offer a thorough examination of grid-connected solar photovoltaic (PV) systems, including solar cells, PV arrays, maximum power point tracking, filters, DC-DC converters, single-phase inverters, and three-phase inverters.	Exceptional dynamic properties, significant current amplification at the resonant frequency, and minimal steady-state discrepancy between the controlled signal and its reference.	The rapid expansion of capabilities, the growing intricacy, and the rising expenses.

Kefale <i>et al.</i> 2021,	To optimize the design of a grid-connected solar photovoltaic system in Ethiopia's radial distribution network.	Enables better performance in the distribution network by determining the proper size and site of solar power installation.	None mentioned
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2.1.2 Power Quality Issues in Grid-Connected Solar PV Systems

In 2023, Rashwan *et al.* [8] involved a newly developed buck-boost inverter with a single energy storage component. The recommended configuration consists of two sequential stages that are interconnected through a high-frequency transformer. The first stage incorporates a newly developed buck-boost inverter with a single energy storage component. This buck-boost inverter displays the ability to convert the output voltage of the photovoltaic (PV) module into a high-frequency square wave (HFSWV) and effectively enhance the maximum power point tracking (MPPT) feature, even in the presence of significant variations in the PV voltage. The high-frequency transformer provides galvanic isolation to the system, resulting in a decrease in leakage current and an improvement in the power quality of the overall system. The second stage of the proposed topology involves the utilization of a rectifier-inverter system to interface the generated HFSWV with the utility grid. The recommended method utilizes a high switching frequency, which provides the advantages of increasing power density, reducing the size of the grid filter, and improving the reliability of the system. To accomplish this, the buck-boost DC/AC inversion technique, MPPT, and low grid current injection are implemented.

In 2023, Jha and Shaik [9] provided a comprehensive review of various power quality challenges associated with SPV penetration and PQ mitigation techniques involving various DFACTS devices and control algorithms such as conventional control, adaptive control, and AI-based control algorithms. More than 130 research articles have been rigorously assessed, categorized, and listed in this article for quick reference for the advantage of engineers and academicians working in this area of research. This results in a scenario of PV integration into a weak AC grid. However, solar integration into a weak AC grid provides power quality (PQ) challenges that limit the penetration levels. The other components which limit penetration levels include non-linear loads, dynamic loads, variable irradiances and partial shading etc. Various DFACTS devices in association with different conventional, adaptive and AI-based algorithms have been proposed in this article to mitigate PQ challenges associated with a weak grid to enhance penetration levels of Solar PV.

In 2023, Liu *et al.* [10] analyzed a strategy that applies Bi-directional LSTM (BDLSTM) artificial neural network. BDLSTM considers the past and future context of the data. The future hidden layer processes input in ascending order, while the past hidden layer evaluates input in decreasing order, making BDLSTM useful for analyzing past context and predicting the future. The weather dataset for this study was obtained from NASA and covers eleven years (2010–2020). Two pre-processing methods, ATSD and Pearson correlation, were used to eliminate noisy values and select features. A

cloud-based server is included in the architecture for data management and future predictions. The cloud-based server is also used for monitoring solar energy data in multi-energy systems. The BDLSTM has been shown to perform effectively on the available data based on the metrics and results obtained. The study's quality and reliability were confirmed using data from two different climatic horizons.

In 2022, Prasad and Dhanamjayulu [11] This article introduces a solar photovoltaic (PV) integrated dynamic voltage restorer (DVR) that utilizes a rotating dq reference frame controller in order to enhance power quality concerns. The primary concentration of this document is on the implementation of an improved incremental conductance maximum power point tracking (INC MPPT) technique and the creation of an effective proportional-integral (PI) controller for the DVR to significantly enhance power quality. The employment of the ANFIS provides for the optimal setting of the PI controller. Additionally, a comprehensive mathematical analysis is performed on the proposed solar PV system, boost converter, and rotating dq reference frame control. The dynamic performance of the system is evaluated under the presence of a balanced load. The performance of the suggested system is then validated in real-time using MATLAB/SIMULINK software, and the Opal-RT platform precisely replicates real-world hardware with the support of FPGA processors. The obtained results demonstrate the effectiveness of the design in mitigating voltage sag, swell, and total harmonic distortion (THD%) levels at the load side, thereby adhering to the IEEE standard ceiling limit.

In 2023, Lavanya *et al.* [12] proposed a procedural approach to assess the effectiveness of the solar power system installed on the rooftop of a college building in Tamil Nadu, India. The paper outlines a systematic approach to evaluating the system's performance and its annual output. The evaluation is conducted in four stages, specifically viability evaluation, energy production evaluation, lifecycle evaluation, and power quality evaluation. In order to enhance the performance and efficiency of the solar PV system, various factors such as solar irradiation, temperature, and wind velocity are taken into consideration, and the PV yield is measured to evaluate the system's energy metrics. The paper also considers the carbon credits earned, the amount of solar power generated, and the payback period. Finally, a power quality assessment is conducted to assess the conformity of the PV plant to efficient grid integration.

In 2023, Pidikiti *et al.* [13] proposed a controller was assessed under various loading conditions in a solar photovoltaic (PV) grid system with a single stage 1 MW rating in this manuscript. Moreover, the suggested system is equipped with local loads and their reactive compensation is assessed through hardware-in-loop on the OPAL-RT software platform. In PV systems, DC-to-DC converters are employed to track the maximum power point; nevertheless, an inverter circuit is indispensable for grid synchronization and can be utilized to extract maximum power from PV systems by implementing appropriate control techniques. Proper control of the inverter is unlikely to eliminate the necessity for DC-to-DC power converters for maximum power point tracking. Nevertheless, this technology is suitable for small-scale solar power plants. The irregular irradiance of solar energy poses a challenge for solar systems. To deal with this issue, a TSKF controller is formulated in this investigation to regulate the operation of the inverter. The TSKF controller exhibits superior responsiveness to rapid

changes in solar irradiance compared to conventional proportional integral controllers.

In 2023, Kırçiçek and Aktaş [14] suggested control algorithm has the ability to detect the active and reactive power of the load while the PV system's inverter functions in filter mode. The examination identifies four conceivable operating situations for the suggested grid-connected PV system. The AEMA is capable of detecting these operating scenarios of the system. Furthermore, the proposed control algorithm possesses the ability to identify the active and reactive power of the load, while the inverter in the PV system functions in filter mode. Furthermore, the proposed control algorithm allows the PV system to generate both active and reactive power, as well as providing reactive power support to the grid. The AEMA, in conjunction with the PQ algorithm, detects when the load requires reactive power and generates reference current signals for the inverter. This study combines the advantages of clean energy generation from PV systems with efforts to enhance power quality in the grid. To demonstrate the effectiveness of the proposed control algorithm, an experimental setup of a single-phase grid-connected PV array with a capacity of 2.1 kW was arranged, and the results were confirmed using a power quality and energy analyzer. Table 2.2 shows the reviews by different authors about Power Quality Issues in Grid-Connected Solar PV Systems

Table 2.2: Analysis of Power Quality Issues in Grid-Connected Solar PV Systems

Authors	Aim	Advantages	Disadvantages
Rashwan <i>et al.</i> 2023,	To introduce a new single-phase photovoltaic (PV) grid connection system that comprises two cascaded stages linked by a high-frequency transformer.	Increased power density leads to smaller grid filter size because of high switching frequency.	None mentioned
Jha and Shaik 2023,	To present a thorough examination of power quality difficulties linked with solar PV integration into a feeble AC grid and to suggest methods for power quality reduction utilizing different DFACTS devices and control algorithms.	Tackling climate change and lowering energy costs; Enhancing power supply reliability.	Non-linear loads, dynamic loads, variable irradiances, and partial shading are factors that further restrict the penetration levels.
Liu <i>et al.</i> 2023,	To propose a cloud-based Bi-directional LSTM approach to grid-connected solar PV energy forecasting for multi-energy systems	Efficiency	None mentioned

Prasad and Dhanamjayulu 2022,	To present a solar PV integrated Dynamic Voltage Restorer (DVR) using a rotating dq reference frame controller to improve power quality issues.	Cost-effective, Efficient PI controller design for DVR enhances power quality performance.	None mentioned
Lavanya <i>et al.</i> 2023,	To analyze the performance of a 100-kW grid-tied PV system installed on a university building rooftop in Tamil Nadu, India.	Enables PV yield measurement and energy metric evaluation to improve solar PV system efficiency.	periodic monitoring
Pidikiti <i>et al.</i> 2023,	To design and control a Takagi-Sugeno-Kang fuzzy (TSKF) based inverter for power quality improvement in grid-tied PV systems.	Easy to install and maintain, clean energy source and environmentally friendly	Conventional PI controllers may struggle with large input changes, causing performance problems.
Kırçiçek and Aktaş 2023,	To build an adaptive energy management algorithm (AEMA) that possesses the capacity to govern active and reactive power for grid-connected photovoltaic (PV) systems.	The control algorithm identifies active and reactive power needs and generates current signals for the inverter.	None mentioned

2.1.3 Harmonics Analysis and Mitigation in Grid-Connected Solar PV Systems

In 2023, Carretero-Hernandez *et al.* [15] investigated the distribution of current harmonics throughout the entire range, as well as the correlation between the values of each harmonic and the power level produced by the inverter or substation. The aim of this investigation is to analyze the distribution of present harmonics across the entire spectrum, as well as the relationship between the values of each harmonic and the power level generated by the inverter or substation. Additionally, we investigate the correlation between voltage and current harmonics. Interestingly, despite operating under the same loading and grid conditions, we observe significant differences in the harmonic emission of the inverters. However, our findings for the substations align with those obtained for the inverters. This study was not conducted in a 12 MW photovoltaic power plant that is connected to the electricity grid and located in Europe.

In 2023, Rashwan *et al.* [16] proposed setup consists of two successive stages connected by a high-

frequency transformer. The proposed configuration consists of two consecutive stages connected by a high-frequency transformer. In the initial stage, a newly designed buck-boost inverter with a single energy storage component is employed. The inverter's lack of ability to convert the output voltage of the PV module into a high-frequency square wave (HFSWV) hampers effective maximum power point tracking (MPPT) even in the presence of significant variations in the PV voltage. The high-frequency transformer provides galvanic isolation to the system, reducing leakage current and enhancing the power quality of the overall system. The second stage of the configuration involves the use of a rectifier-inverter system to interface the generated HFSWV with the utility grid. The operational principles of the proposed configuration have been extensively investigated and the theoretical and experimental findings have been thoroughly developed and analyzed.

In 2023, Bhushan and Sudhakaran [17] scrutinized the importance of time-series load flow analysis (LFA) in the context of a real-time power distribution network in the Puducherry smart grid system. It specifically considers the seasonal load variations that occur in the union territory of Puducherry, India, with the aim of attaining optimal performance. To achieve this objective, the load flow analysis is employed on various test systems, namely IEEE 69, IEEE 37, IEEE 34, and the Indian utility 29 node distribution network (IU29NDN) within the Puducherry smart grid system. These test systems are characterized by unbalanced load patterns and energy sources in close proximity. In order to enhance voltage profiles within distribution networks, a Modified Decision Making (MDM) algorithm is introduced in this paper. This algorithm focuses on selecting the appropriate size and location of solar photovoltaic (SPV) systems. By subjecting distribution networks to quasi-dynamic load flow simulations conducted over a period of 24 hours with a 15-minute step size, estimations are made regarding the variations in node voltages, real power, and reactive power flows resulting from seasonal load fluctuations.

In 2023, Mathew and Naidu [18] provided a thorough examination and comparison of different topologies in terms of their performance, cost, size, durability, and requirements for connecting to the grid at a reference power level of 200 W. It carries out a comprehensive analysis and comparison of various topologies in terms of their performance, cost, size, durability, and grid connection requirements at a reference power level of 200 W. The examination of MPPT techniques is founded on their complexity, robustness, and precision. This publication presents an outline of the Low Voltage AC (LVAC) scheme connected in series, as well as several areas that have potential for further research. By offering insightful analysis and ideas for development, this article equips researchers with the knowledge needed to design and create optimized single-stage PV systems that are more efficient and effective.

In 2022, Hussein *et al.* [19] examined the mechanism behind the generation and emission of interharmonics under various power operating conditions. In light of this investigation, a novel approach to mitigating interharmonics generation in grid-connected PV systems is introduced. The proposed technique involves modifying the MPPT algorithm in a manner that preserves its performance characteristics while effectively minimizing the production of interharmonics. This is achieved by utilizing a random selection of perturbation step sizes, either large or small, and a

sampling rate that can be either fast or slow. Consequently, the frequency spectrum distribution is altered, resulting in a 27% reduction in interharmonic peaks in the current injected into the grid, when compared to other conventional and modified perturb and observe (P&O) MPPT algorithms documented in the existing literature. The efficiency of this suggested approach was established through simulation studies conducted on a single-phase grid-connected solar panel system.

In 2023, Abo-Khalil *et al.* [20] This article presents a study examining the means to regulate the variability inherent in the production of electricity from solar energy, as well as enhance the incorporation of this type of production for self-consumption in an installation. In this regard, alongside an investigation into the legislative framework governing self-consumption activities, subjects such as energy storage, photovoltaic generation, and the optimization of production systems with storage were explored. The determination of the dimensions of a grid-connected photovoltaic system relies on the choice and appropriateness of the module, DC/AC inverter, and other associated equipment. The inverter sizing factor denotes the relationship between the inverter's power and that of the PV generator, its selection contingent upon various factors. Furthermore, this work not only aims to present a study on the economic feasibility of this technology for the chosen edifice but also endeavors to provide a means of assessing its profitability. Table 2.3 represents the reviews by various authors about the Harmonics Analysis and Mitigation in Grid-Connected Solar PV Systems

Table 2.3: Harmonics Analysis and Mitigation in Grid-Connected Solar PV Systems

Authors	Aim	Advantages	Disadvantages
Carretero-Hernandez <i>et al.</i> 2023,	To evaluate each harmonic's value in relation to the power output of the inverter or substation, as well as the distribution of harmonics that are now present over the full spectrum.	Low emission	None mentioned
Rashwan <i>et al.</i> 2023,	To demonstrate a fresh method of connecting a single-phase PV system to the grid.	The use of high switching frequency results in higher power density and smaller grid filters.	None mentioned

Bhushan and Sudhakaran 2023,	To perform time-series quasi-dynamic load flow analysis with seasonal load variation in a practical distribution network in the Puducherry smart grid system, incorporating harmonic analysis and mitigation.	Aids in recognizing the harmonic production in different parts of the distribution system caused by the inclusion of solar photovoltaic (SPV).	Optimizing the placement and sizing of renewable energy sources and mitigation devices is challenging due to the need to balance multiple objectives and constraints.
Mathew and Naidu 2023,	To provide a comprehensive review of single-phase boost inverter technology for low power grid integrated solar PV applications.	Cost-effective, provides methods for optimal power generation control, including voltage and current control.	CSI has the disadvantage of employing one-way switches and large inductors, impeding their commercialization.
Hussein <i>et al.</i> 2022,	To explore the process of interharmonics creation and discharge in grid-connected PV systems and recommend a technique to minimize interharmonics peaks in the current supplied to the grid.	The output injected current to the grid is reduced by 27% compared to other conventional and modified MPPT algorithms by reducing interharmonics peaks.	It is challenging to evaluate the effectiveness and dependability of the suggested approach in real-world scenarios without conducting experimental verification.
Abo-Khalil <i>et al.</i> 2023,	to assess the economic feasibility and profitability of the technology for the selected building	Photovoltaic modules are improving in efficiency due to advancements in manufacturing and materials. The efficiency of photovoltaic modules is expected to increase over time.	The integration of solar power systems into the grid necessitates adherence to technical, quality, and safety standards, potentially resulting in added expenses and regulatory intricacies.

2.1.4 Impact of Solar PV System Size on Power Quality in Grid Integration

In 2023, Gelchu *et al.* [21] evaluated the cost-efficiency implications of implementing demand-side management (DSM) at a categorical level. A shifting approach is employed based on the classification of loads into high priority and low priority categories. Through the utilization of particle swarm optimization, the sizing of autonomous rural mini-grid components is conducted for four distinct load categories and load flexibility. The findings indicate that different combinations of load categories yield significant variations in terms of potential reductions in levelized energy costs and, consequently, in the optimal sizing of the mini-grid components. Notably, the implementation of DSM within the household and productive use categories exhibits the greatest capacity for reducing levelized energy costs, with reductions of 45.8% and 20.7%, respectively, when compared to the scenario without demand-side management.

In 2023, Yadav *et al.* [22] utilized the Incremental Conductance (IC) and Perturb and Observe (P&O) algorithms, which have gained marginal acceptance in the industry and are not readily implementable. The objective of this investigation is to devise and compare a Step Voltage (SV) controller and a Step-Duty (SD) Maximum Point Tracking (MPPT) IC controller-based DC to DC boost converter. The article juxtaposes the performance of SV and SD controller-based DC to DC boost converters under varying environmental circumstances, appraises the effectiveness of the system by comparing the fluctuations in load power for both conditions, and explores the ramifications of battery charging on the load. The system's performance is assessed employing MATLAB Simulink/coding, taking into account the scenario of Indian solar radiation intensity (SRI) and temperature fluctuations. In conclusion, this study provides a comprehensive analysis of the performance of the proposed system, which has the potential to contribute to the advancement and optimization of solar energy systems in various applications.

In 2023, Ullah *et al.* [23] examined the functioning and regulation of intelligent inverters (SI) for solar and solar-plus-storage systems, with a particular focus on Volt-VAR Control (VVC) at solar interconnections. The study presents technological and economic recommendations for both standard-sized and oversized solar inverters equipped with VVC. The aim is to minimize voltage violations and active power curtailment by providing reactive power support to the grid while adhering to the IEEE 1547-2018 standards. Additionally, a collaborative VVC approach is evaluated, in which a battery storage system is combined with the solar facility, a configuration that is gaining popularity for enhancing energy resilience in communities. To simulate an unbalanced distribution network, a modified version of the IEEE 13-bus system is used, with three 700 kW solar PV plants connected through smart inverters. The solar data utilized in this study is obtained from the University of Louisiana's 1.1 MW solar farm and is categorized into 28 clusters.

In 2022, Peprah *et al.* [24] examined the appropriateness of utilizing reactive power support (RPS) and solar photovoltaics in order to achieve active voltage management, minimize power loss, and decrease transformer capacity in prosumer grids employing the python optimization algorithm. The findings indicate that the injection of solar photovoltaic energy and the compensation for reactive

power have both positive and negative effects on the prosumer grid. The operation of the grid with the injection of solar photovoltaics and reactive power support, while utilizing transformers with specific capacities, does not result in over-voltage and excessive power loss issues. The results obtained from the various scenarios demonstrate that operating the grid as a consumer grid leads to greater power loss compared to operating it with the injection of solar photovoltaics and reactive power support.

In 2021, Kreuwel *et al.* [25] presented a comprehensive analysis of overvoltage incidents associated with solar photovoltaic (PV) systems, with a specific focus on their spatial and temporal characteristics. The investigation utilizes innovative data sources, including over 200,000 events obtained from advanced metering infrastructure (AMI) covering one-third of the Netherlands, as well as satellite observations and 1-minute measurements of irradiance. Consequently, the study reveals that overvoltage events typically last approximately 5 minutes, and meters that report such events are scattered across different geographical locations. Although high PV generation is the main driver of overvoltages, there is no evidence to suggest that local, short-term peaks in irradiance lead to additional incidents compared to clear sky conditions. Interestingly, the study reveals a higher frequency of overvoltage events on Sundays, with a median occurrence rate more than 2.1 times higher than on weekdays, which can be attributed to lower energy consumption. The findings also indicate that the PV hosting capacity is reached simultaneously across the entire service area and that neither inverter control nor grid control reduces the duration of these events. It should be noted that despite a significant increase in the frequency of overvoltage incidents, they remain relatively rare, with only 0.1% of the AMI reporting more than 10 events during the spring-summer period of 2020.

In 2023, Peprah *et al.* [26] examined the financial viability and profitability associated with various types of prosumers in Ghana's residential and commercial sectors. To evaluate the financial feasibility and profitability of electricity prosumption in Ghana, the economic indicators utilized include net present value, internal rate of return, profitability index, and discounted payback. The findings of the research indicate that investing in electricity prosumption in Ghana is a worthwhile endeavor. Among the different investment options available in the residential and commercial classes, the most favorable choice is prosumers with grid integration and without storage (type 2). Furthermore, within the residential tariff class, the optimal investment option is prosumers whose energy demands fall within the range of 301 kWh to 600 kWh. Table 2.4 reviews by various authors about the Impact of Solar PV System Size on Power Quality in Grid Integration

Table 2.4: Impact of Solar PV System Size on Power Quality in Grid Integration

Authors	Aim	Advantages	Disadvantages
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Gelchu <i>et al.</i> 2023,	To examine the influence of demand-side management (DSM) on the cost-effectiveness of autonomous solar PV-based mini-grids in rural regions.	The implementation of DSM has a more pronounced effect on the reduction of the LEC in contrast to solar PV and diesel-fueled generators.	None mentioned
Yadav <i>et al.</i> 2023,	To design and compare a Step Voltage (SV) controller and a Step-Duty (SD) Maximum Point Tracking (MPPT) IC controller-based DC to DC boost converter for a solar PV system.	The IC SD controller in the system performs exceptionally well.	None mentioned
Ullah <i>et al.</i> 2023,	To investigate the operation and control of smart inverters (SI) for solar and solar-plus-storage systems with a focus on Volt-VAR Control (VVC) at solar interconnections.	Enhances energy resilience in communities by providing support for reactive power to the grid.	Frequent VVC may negatively affect the solar inverter's lifespan due to additional thermal stress.
Peprah <i>et al.</i> 2022,	To analyze the suitability of using reactive power support (RPS) and solar photovoltaics (PV) to achieve active voltage management, minimize power loss, and reduce transformer capacity in prosumer grids PV using the python optimization algorithm	Active voltage management, power loss reduction, and transformer capacity reduction in prosumer grids.	The placement of reactive power compensators on the low voltage prosumer grid is a difficult task in order to reduce voltage deviation and line loss.
Kreuwel <i>et al.</i> 2021,	To examine overvoltage incidents associated with solar photovoltaic (PV) systems and comprehend their connection with cloud conditions and variability in irradiance.	Offers a description of overvoltage events associated with solar PV systems in terms of space and time.	None mentioned

Peprah <i>et al.</i> 2023,	to examine the economic aspects linked to various categories of prosumers within Ghana's residential and commercial sectors.	Prosumers with energy demands of 301 kWh to 600 kWh are the optimal investment for residential tariff class.	Maintenance requirements
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2.2 Conclusion

The paper provided a comprehensive analysis of solar PV systems that are interconnected with the electrical grid, artificial intelligence methods, RAM performance, voltage stability improvement, and harmonic dispersion in inverters and substations. The pros and cons of various control strategies and system configurations for solar PV systems that are linked to the power grid are examined in this article. The essay also emphasized the potential benefits of artificial intelligence technology along the whole solar value chain, from design to forecasting to control to maintenance. The performance of solar photovoltaic (PV) systems linked to various voltage grids is modeled in the article using a special MATLAB Simulink model. The article analyzed the innovative approach to assess reliability, availability, and maintainability in practical solar PV systems connected to the power grid and optimize the costs associated with maintenance. The article assessed the use of large-scale solar PV systems to enhance the stability of voltage in weak national power grids. The article explored the generation and mitigation of interharmonics in solar PV systems that are connected to the power grid and recommends a modified maximum power point tracking algorithm to minimize their production. The essay concluded by looking at how intelligent inverters for solar systems and solar-plus-storage systems operate and are regulated, with an emphasis on reactive power support and Volt-VAR control.

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