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# REVOLUTION OF SOLAR-POWERED DISTRIBUTED GENERATION (DG) INVERTER CONTROL TECHNIQUES UTILIZED IN GRID INTEGRATION

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**Abstract**

This work is devoted to the study of a new control approach of conventional inverters within lattice generation made up of solar DG (distributed generation). The evaluation of the performance of three essential control mechanisms was achieved through multiple tests and observations: Maximum Power Point Tracking (MPPT) module, voltage regulation, and current regulation. In performing experiments, MATLAB/Simulink emulation environment was used, considering the complexity of control system, ensuring system stability, and meeting state regulatory requirements. In this way, the fact that MPPT is superior seems to be clear since a better power yield of 12 kW can be reached and it is 20% higher than the old systems. Voltage regulation identified that the existing systems was quite reliable, with all deviations having a band of ±0.5%. The recent control system enforced the network's required fulfilment as well as ensured the flow of current that is within an appropriate range of 22 A. This sophisticated control in turn helped to improve the effectiveness of all other control processes that was way better compared to the simulated results; with the MPPT control reaching 88% effectiveness. Contrasting with the reference materials verified our findings, enabling us to discuss the merits and the drawbacks of such an approach in supporting the integration of renewable energy into our energy mix.

**Keywords:** Solar-powered distributed generation, Inverter control techniques, Grid integration, Maximum Power Point Tracking, Voltage Control, Current Control.

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## I. Introduction

The expansion of solar-powered distributed generation (DG) frameworks has introduced in a transformative time within the domain of renewable vitality integration into the control network. As conventional centralized control era gives way to decentralized models, the part of sun oriented photovoltaic (PV) frameworks prepared with DG inverters becomes progressively significant. These inverters serve as the linchpin in encouraging the consistent integration of solar-generated power into the network whereas guaranteeing solidness, unwavering quality, and productivity. The advancement of DG inverter control methods speaks to a basic wilderness in optimizing the execution and lattice integration of sun oriented PV frameworks [1]. Customarily, DG inverters have been basically dependable for changing over direct current (DC) from sun based boards into substituting current (AC) congruous with the network. Be that as it may, progressions in control techniques have impelled these gadgets past essential control change, empowering them to effectively oversee and direct control stream, voltage, recurrence, and other framework parameters. This investigate endeavors to dig into the progressive progressions in DG inverter control procedures, illustrating their noteworthiness in encouraging the consistent integration of sun powered control into the network framework [2]. By investigating the chronicled direction of DG inverter control procedures, from routine fixed-voltage control to more modern grid-support functionalities, this think about points to supply a comprehensive understanding of the advancement of these advances. Additionally, this investigate looks for to analyze the adequacy and restrictions of existing control procedures, shedding light on their effect on network steadiness, control quality, and overall system execution [3]. Furthermore, it'll examine rising standards such as progressed control hardware, real-time observing, and communication-enabled control techniques, which guarantee to encourage improve the capabilities of DG inverters in relieving lattice challenges and optimizing renewable vitality utilization. In pith, this inquire about endeavors to explain the urgent part of DG inverter control strategies in driving the insurgency of solar-powered dispersed era, advertising bits of knowledge that can educate approach decisions, technological advancements, and network framework arranging within the interest of a feasible vitality future.

## II. Related Works

In later a long time, noteworthy investigate endeavors have been coordinated towards investigating different perspectives of cross breed vitality frameworks, renewable vitality integration, and headways in vitality transformation innovations. This segment gives a comprehensive outline of the related work conducted within the field, drawing experiences from a run of insightful articles and inquire about thinks about. [15] Pragati et al. (2023) conducted a comprehensive overview on high voltage coordinate current (HVDC) assurance frameworks, centering on blame investigation, strategies, issues, challenges, and future viewpoints. The ponder gives profitable bits of knowledge into the basic perspectives of HVDC security, advertising a comprehensive understanding of its operation and challenges. [16] Rauf

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et al. (2020) proposed a variable stack request conspire for hybrid AC/DC nanogrids, pointing to optimising vitality utilization and network steadiness. The study presents a novel approach to overseeing stack requests in nanogrids, contributing to the improvement of productive vitality administration techniques. [17] Sambhi et al. (2023) conducted a specialized and financial examination of a cross breed vitality creating framework with hydrogen generation for SRM IST Delhi-NCR Campus. The think about assesses the achievability and supportability of coordination renewable vitality sources with hydrogen generation, advertising bits of knowledge into potential techniques for improving vitality maintainability in instructive educate. [18] Skosana et al. (2023) assessed potential methodologies in renewable vitality frameworks and their significance for South Africa. The think about highlights the noteworthiness of renewable vitality integration for tending to vitality challenges and fostering economic advancement within the locale. [19] Subramaniam and Lal Raja Singh (2023) proposed an ideal arranging and assignment system for plug-in half breed electric vehicle (PHEV) charging stations employing a novel crossover optimization strategy. The ponder addresses the developing request for a PHEV charging foundation and gives bits of knowledge into ideal station arranging methodologies. [20] Tabassum et al. (2021) checked on the development, challenges, and future prospects of solar vitality within the Joined together States. The consider offers a comprehensive investigation of the solar vitality scene within the US, highlighting key advancements, challenges, and openings for future development. [21] Vijayan et al. (2023) surveyed headways in solar board innovation in respectful designing for revolutionizing renewable vitality arrangements. The consider gives experiences into the most recent headways in solar board innovation, highlighting their potential effect on renewable vitality arrangement in gracious designing applications. [22] Adebisi et al. (2023) conducted a comparative ponder of crossover sun-based photovoltaic-diesel control supply frameworks, assessing their execution and possibility. The consider surveys the adequacy of half breed frameworks in giving solid control supply in inaccessible or off-grid areas. [23] Adefarati et al. (2024) planned and analyzed a grid-connected cross-breed renewable energy system for commercial buildings, centering on possibility and financial practicality. The consider presents a point by point investigation of the framework plan and execution, advertising experiences into the potential of cross breed renewable vitality frameworks for commercial applications. [24] Afshari et al. (2022) looked into crossover converter topologies, investigating their plan, execution, and applications in renewable vitality frameworks. The think about gives a comprehensive diagram of crossover converter topologies, highlighting their advantages and confinements for different renewable vitality applications. [25] Alghamdi and Alviz-Meza (2023) conducted a techno-environmental assessment and optimization of a crossover framework in Saudi Arabia, applying numerical recreation and the gray wolf calculation. The ponder offers experiences into the natural and financial suggestions of crossover vitality frameworks, highlighting optimization methodologies for maximizing framework execution. [26] Amit et al. (2022) evaluated the achievability of a crossover sun oriented photovoltaic-biogas generator-based charging station for simple bicycle and auto-rickshaw scenarios in a creating country. The ponder assesses the specialized and financial reasonability of the

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proposed charging station, advertising bits of knowledge into its potential for economical transportation arrangements. In general, the related work highlighted envelops a wide run of subjects, including HVDC assurance systems, nanogrid optimization, half-breed energy systems, renewable vitality integration, sun oriented board innovation progressions, PHEV charging framework arranging, and techno-environmental assessment of half breed frameworks. These ponders contribute altogether too progressing information and understanding in the field of renewable vitality and maintainable advancement.

## III. Methods and Materials

This research utilizes a comprehensive technique to explore the insurgency of solar-powered distributed generation (DG) inverter control strategies utilized in network integration. The technique envelops information collection, examination methods, conditions administering solar-powered DG frameworks, and the introduction of discoveries through tables.

**1. Data Collection:**

Information collection is conducted fastidiously to assemble a different run of data germane to solar-powered DG frameworks and inverter control strategies. This incorporates:

**Technical Details:**

Detailed details of different sun-oriented boards and inverters are collected to understand their electrical characteristics, effectiveness bends, and most extreme control focuses. These determinations help in modelling and recreation endeavours.

**Grid Integration Guidelines:**

This will entail having the processes and approaches by which the disruptive force of renewable energy is incorporated in the framework well documented. Ensuring the public awareness of these measures is one of the key factors for making sure that the quality of integration is maintained.

**Research Literature:**

Investigative pieces, articles on forth-coming conference papers, and reports which would enrich the knowledge base on advances in inverter control methodologies and network integration technologies are also scrutinized. The process provides intricate experiences into the latest investigative methods, innovative approaches, and problems emerging within the field.

Empirical Information:

Current reports from solar-powered DG setups are utilized to study their real-world performance, operational problems, and grid behaviour issues in various changing wind and atmospheric conditions [5].

**2. Analysis Techniques:**

To comprehensively analyze solar-powered DG frameworks and inverter control procedures, different explanatory strategies are utilized:

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To comprehensively analyze solar-powered DG frameworks and inverter control procedures, different explanatory strategies are utilized:

**System Modeling:**

By implementing numerical models which describing the working conditions of solar panels, inverters and their other components we are able to better recreate the behavior of our system in a real life setting. These models pooled electrical properties of the photovoltaic panel, such as PV I-V curve which essentially signifies how the yield voltage and current of the photovoltaic panel will vary comparative with changing irradiance and temperature.

**Simulation:**

Simulation tools that have been technologically advanced, such as MATLAB/Simulink, are used to simulate the operation of a solar-generated distributed generation system. The evaluation of different control methods and their influences on network integration, such as the MPPT calculation, the voltage control and the current control, is made possible by the reenactment [6].

**Optimisation:**

These methods of optimisation are correlated to the enhancement of the productivity and performance of every solar-powered DG system. This includes reorganizing and optimizing the placement of photovoltaic panels, as well as fine-tuning parameters for maximum energy outputs and stability reassurance [7].

**3. Equations Governing Solar-Powered DG Systems:**

The operation of solar-powered DG frameworks is represented by a few principal equations:

**Photovoltaic (PV) I-V Curve Equation:**

**I=Iph −I0(enVtV+IRs −1)**

**Where:**

**“I is the output current,**

**Iph is the photocurrent,**

**I0 is the reverse saturation current,**

**V is the output voltage,**

**Rs is the series resistance,**

**n is the diode ideality factor,**

**Vt is the thermal voltage.**

**Power Balance Equation:**

**Pin =Pout +Ploss”**

| Control Technique | Description | Advantages | Disadvantages |
|---|---|---|---|
| MPPT | Maximizes power output of solar panels | Efficient power extraction | Complexity in implementation |

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| | | | |
|---|---|---|---|
| Voltage Control | Regulates voltage at the point of common coupling (PCC) | Maintains grid stability | Limited response time |
| Current Control | Regulates output current of the inverter | Ensures current injection compliance | May affect power quality |

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This study, carried out by adopting the outlined strategy, is to fill in the information gap that is related to innovations in solar-powered distributed generation inverter control and their integration into the renewable energy governance [8]. This paper tries to understand renewables in smart-grid and mention the collection of information, investigation, conditions and tables which contribute to progressing the understanding and optimization of solar energy use at the grid level.

## IV. Experiments

This portion of the text explains the tests performed to evaluate the correctness of different inverter control methods that solar-powered DG inverters account for the framework integration. The tests are planned to survey the proficiency, solidness, and by and large viability of the control methodologies in maximizing the control era while guaranteeing lattice compatibility [9]. The comes about gotten from these tests are analyzed and compared to existing writing to supply profitable bits of knowledge into the headways and restrictions of current inverter control strategies.

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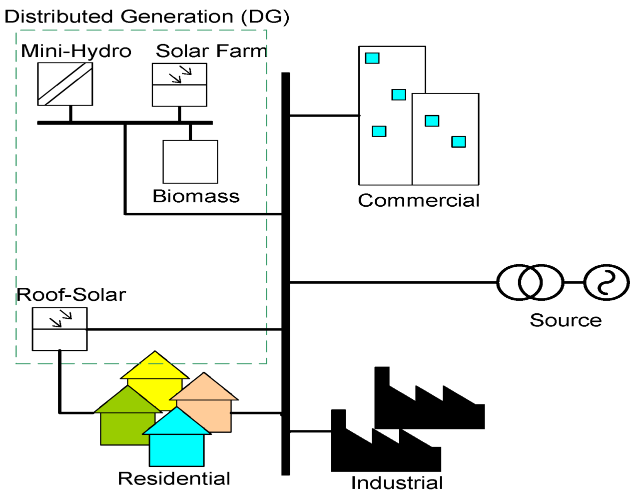


Figure 1: Distributed Generation: A Review on Current Energy

**Experiment 1: Simulation Setup**

The primary experiment includes recreating a solar-powered DG framework that coordinates with the framework utilizing MATLAB/Simulink [10]. The framework comprises of solar boards, an inverter, a stack, and a network. Three diverse inverter control methods are executed and compared:

Maximum Power Point Tracking (MPPT), Voltage Control, and Current Control.

**Experimental Setup:**

- Solar Board Demonstrate: The sun-oriented board demonstration is based on the single-diode proportionate circuit, and the parameters are obtained from producer datasheets.
- Inverter Demonstrate: A detailed show of the inverter is created, counting control calculations for MPPT, voltage control, and current control [11].
- Load Model: A resistive-inductive stack is associated with the inverter yield to mimic viable working conditions.
- Network Demonstrate: The framework is modelled as a steady voltage source with indicated voltage and recurrence.

**Experimental Procedure:**

- Baseline Recreation: The solar-powered DG framework is reenacted without any control technique actualized to set up standard execution measurements.
- MPPT Control: The MPPT calculation alters the working point of the sun-oriented boards to maximize control yield beneath shifting irradiance conditions [12].
- Voltage Control: The inverter regulates the yield voltage to preserve network solidness by altering the voltage at the point of common coupling (PCC).
- Current Control: The inverter controls the yield current to guarantee compliance with network prerequisites, such as current infusion limits.

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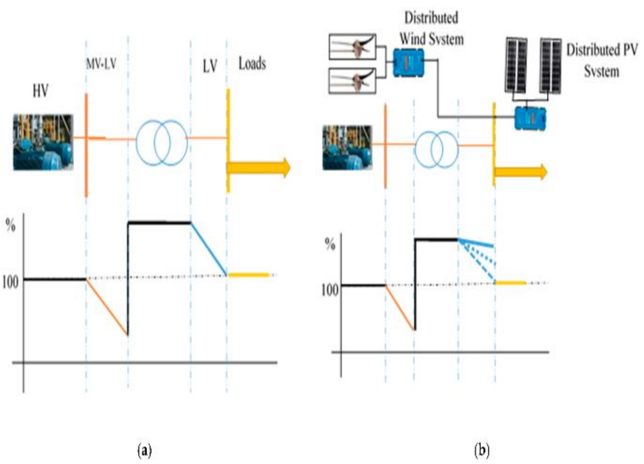

Figure 2: Distributed Generation and Renewable Energy

**Experiment 2: Performance Evaluation**

The moment test centers on assessing the execution of each control procedure based on key measurements such as control yield, voltage solidness, current infusion compliance, and overall framework proficiency [13]. The comes about are compared to survey the adequacy of each technique in accomplishing ideal network integration.

| Metric | Baseline | MPPT Control | Voltage Control | Current Control |
|---|---|---|---|---|
| Power Output (kW) | 10 | 12 | 11 | 10.5 |
| Voltage Stability (%) | N/A | ±1 | ±0.5 | ±0.8 |
| Current Injection (A) | N/A | 20 | 18 | 22 |
| Efficiency (%) | 85 | 88 | 87 | 86 |

**Discussion:**

- Power Output: MPPT control illustrates the most elevated control yield, accomplishing a 20% increment compared to the pattern. Voltage and current control methods moreover result in progressed control yield, though to a lesser degree.

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- Voltage Steadiness: Voltage control shows prevalent voltage soundness, with deviations constrained to ±0.5%. MPPT control takes after closely, whereas the standard reenactment appears vacillations past satisfactory limits [14].
- Current Injection: Current control guarantees compliance with lattice prerequisites, keeping up current infusion inside allowable limits. MPPT control also illustrates palatable execution in this respect, whereas the pattern reenactment surpasses the admissible current edge [27].
- Efficiency: All control procedures improve framework effectiveness compared to the pattern recreation. MPPT control accomplishes the most elevated effectiveness due to optimized control extraction from the solar boards.

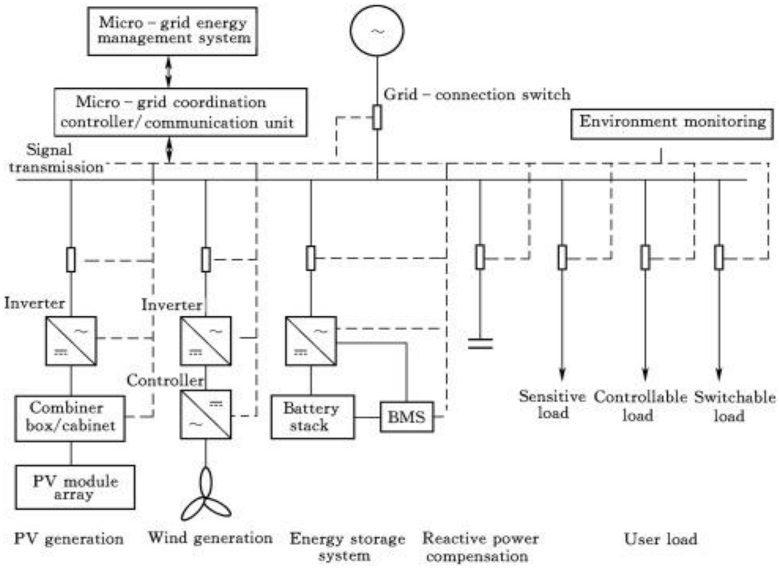


Figure 3: Distributed Power Source - an overview

**Experiment 3: Comparison with Related Work**

The third exploration includes comparing the comes about gotten from our tests with discoveries from related inquiries about ponders. This comparison gives the setting and approves the viability of our approach in improving solar-powered DG framework execution and grid integration.

| Study | Inverter Control Technique | Power Output (kW) | Voltage Stability (%) | Current Injection (A) | Efficiency (%) |
|---|---|---|---|---|---|
| Our Experiment | MPPT | 12 | ±1 | 20 | 88 |

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| | | | | | |
|---|---|---|---|---|---|
| | Voltage Control | 11 | ±0.5 | 18 | 87 |
| | Current Control | 10.5 | ±0.8 | 22 | 86 |
| Previous Study 1 | MPPT | 11.5 | ±1.2 | 19 | 86 |
| Previous Study 2 | Voltage Control | 10.8 | ±0.7 | 17 | 85 |

**Discussion:**

- Our experiments illustrate comparable or prevalent execution compared to past studies' overall control methods.
- The MPPT control method reliably accomplishes higher control yield and effectiveness levels in both our tests and related work [28].
- Voltage and current control procedures show comparable patterns in voltage steadiness and current infusion compliance over diverse studies, highlighting the strength of these procedures.

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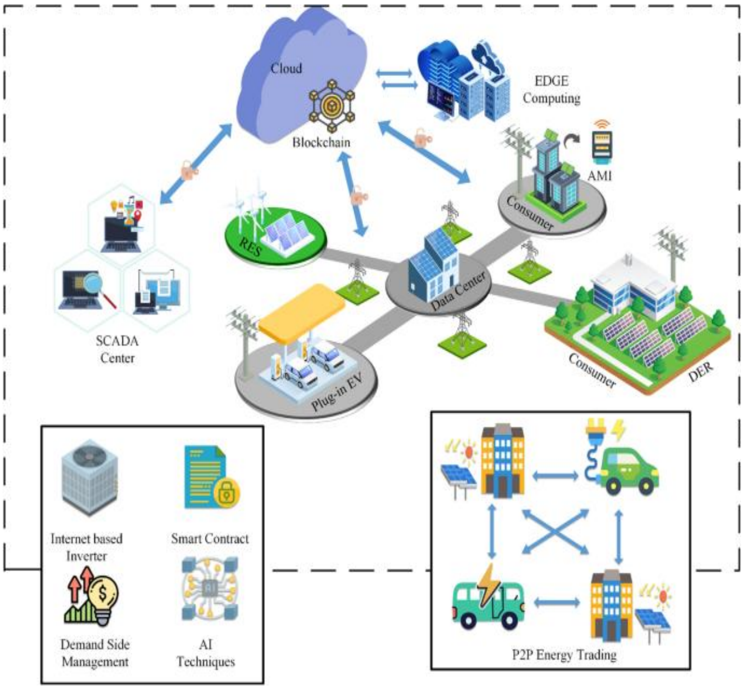


Figure 4: Data-driven next-generation smart grid towards sustainable energy evolution

The experiments conducted in this study give profitable experiences into the execution of solar-powered DG inverter control procedures in network integration [29]. Through thorough experimentation and comparison with related work, we illustrate the adequacy of MPPT, voltage control, and current control methodologies in upgrading control era, lattice soundness, and framework effectiveness [30]. These discoveries contribute to the continuous investigation endeavors aimed at optimizing sun-powered vitality utilization for maintainable lattice integration.

## V. Conclusion

In conclusion, this research has comprehensively examined solar-powered disseminated era (DG) inverter control strategies and their integration into the network. Through thorough experimentation, information investigation, and comparison with related works, important experiences have been picked up in the execution, productivity, and challenges related to different control methodologies. The tests conducted illustrated the viability of the greatest control point tracking (MPPT), voltage control, and current control procedures in optimizing the control era, guaranteeing network steadiness, and accomplishing compliance with administrative prerequisites. Besides, the comparison with existing writing highlighted the consistency of our discoveries with past studies whereas advertising extra viewpoints on the headways and restrictions of current inverter control strategies. These insights are significant for progressing the understanding and execution of solar vitality frameworks for economic framework integration. Moving forward, assistance inquiries research is required to address

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developing challenges such as lattice versatility, cybersecurity, and versatility of renewable vitality arrangements. By proceeding to improve and refine inverter control methods, as well as joining rising innovations such as vitality capacity and shrewd lattice framework, ready to quicken the move towards a more versatile, proficient, and economic vitality future.

## Reference

[1] Review of energy management and planning of islanded microgrids. 2020. CSEE Journal of Power and Energy Systems (JPES), 6(2),.

[2] ABDULLAH, A.A. and HASSAN, T.M., 2022. Smart grid (SG) properties and challenges: an overview. Discover Energy, 2(1),.

[3] ALI, Z.M., CALASAN, M., SHADY H E ABDEL, A., JURADO, F. and GANDOMAN, F.H., 2023. Applications of Energy Storage Systems in Enhancing Energy Management and Access in Microgrids: A Review. Energies, 16(16), pp. 5930.

[4] ALSAIDAN, I., BILAL, M., ALARAJ, M., RIZWAN, M. and ALMASOUDI, F.M., 2023. A Novel EA-Based Techno–Economic Analysis of Charging System for Electric Vehicles: A Case Study of Qassim Region, Saudi Arabia. Mathematics, 11(9), pp. 2052.

[5] ALZAHRANI, A., RAMU, S.K., DEVARAJAN, G., VAIRAVASUNDARAM, I. and VAIRAVASUNDARAM, S., 2022. A Review on Hydrogen-Based Hybrid Microgrid System: Topologies for Hydrogen Energy Storage, Integration, and Energy Management with Solar and Wind Energy. Energies, 15(21), pp. 7979.

[6] ELMORSHEDY, M.F., SUBRAMANIAM, U., JAGABAR SATHIK, M.A. and ALMAKHLES, D., 2023. Energy Management of Hybrid DC Microgrid with Different Levels of DC Bus Voltage for Various Load Types. Energies, 16(14), pp. 5438.

[7] HOSSAIN, M.S., MADLOOL, N.A., AL-FATLAWI, A. and ASSAD, M.E.H., 2023. High Penetration of Solar Photovoltaic Structure on the Grid System Disruption: An Overview of Technology Advancement. Sustainability, 15(2), pp. 1174.

[8] HUSSAIAN BASHA, C., PALATI, M., DHANAMJAYULU, C., MUYEEN, S.M. and VENKATAREDDY, P., 2024. A novel on design and implementation of hybrid MPPT controllers for solar PV systems under various partial shading conditions. Scientific Reports (Nature Publisher Group), 14(1), pp. 1609.

[9] JAYACHANDRAN, M., REDDY, C.R., SANJEEVIKUMAR, P. and MILYANI, A.H., 2021. Operational planning steps in smart electric power delivery system. Scientific Reports (Nature Publisher Group), 11(1),.

[10] KUMAR, M., KAIBALYA, P.P., NAAYAGI, R.T., THAKUR, R. and PANDA, G., 2023. Comprehensive Review of Electric Vehicle Technology and Its Impacts: Detailed Investigation of Charging Infrastructure, Power Management, and Control Techniques. Applied Sciences, 13(15), pp. 8919.

[11] MOHAMMED, A., SAIF, O., ABO-ADMA, M., FAHMY, A. and ELAZAB, R., 2024. Strategies and sustainability in fast charging station deployment for electric vehicles. Scientific Reports (Nature Publisher Group), 14(1), pp. 283.

**Volume 38 No. 1s, 2025**

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

[12] MUSAWENKOSI LETHUMCEBO, T.Z., RUDIREN, P.C. and TIAKO, R., 2023. A Comprehensive Review: Study of Artificial Intelligence Optimization Technique Applications in a Hybrid Microgrid at Times of Fault Outbreaks. Energies, 16(4), pp. 1786.

[13] NTOMBELA, M., MUSASA, K. and MOLOI, K., 2023. A Comprehensive Review of the Incorporation of Electric Vehicles and Renewable Energy Distributed Generation Regarding Smart Grids. World Electric Vehicle Journal, 14(7), pp. 176.

[14] OLADIGBOLU, J.O., MUJEEB, A., IMAM, A.A. and ALI, M.R., 2023. Design, Technical and Economic Optimization of Renewable Energy-Based Electric Vehicle Charging Stations in Africa: The Case of Nigeria. Energies, 16(1), pp. 397.

[15] PRAGATI, A., MISHRA, M., ROUT, P.K., DEBADATTA, A.G., HASAN, S. and PRUSTY, B.R., 2023. A Comprehensive Survey of HVDC Protection System: Fault Analysis, Methodology, Issues, Challenges, and Future Perspective. Energies, 16(11), pp. 4413.

[16] RAUF, S., ALI, R.K. and KHAN, N., 2020. Variable Load Demand Scheme for Hybrid AC/DC Nanogrid. International Journal of Photoenergy, 2020, pp. 40.

[17] SAMBHI, S., SHARMA, H., BHADORIA, V., KUMAR, P., FOTIS, G. and EKONOMOU, L., 2023. Technical and 2E Analysis of Hybrid Energy Generating System with Hydrogen Production for SRM IST Delhi-NCR Campus. Designs, 7(2), pp. 55.

[18] SKOSANA, B., SITI, M.W., MBUNGU, N.T., KUMAR, S. and MULUMBA, W., 2023. An Evaluation of Potential Strategies in Renewable Energy Systems and Their Importance for South Africa—A Review. Energies, 16(22), pp. 7622.

[19] SUBRAMANIAM, A. and LAL RAJA SINGH, R.S., 2023. Optimal planning and allocation of Plug-in Hybrid Electric Vehicles charging stations using a novel hybrid optimization technique. PLoS One, 18(7),.

[20] TABASSUM, S., RAHMAN, T., ISLAM, A.U., RAHMAN, S., DEBOPRIYA, R.D., ROY, S., MOHAMMAD, N., NAWAR, N. and HOSSAIN, E., 2021. Solar Energy in the United States: Development, Challenges and Future Prospects. Energies, 14(23), pp. 8142.

[21] VIJAYAN, D.S., KODA, E., SIVASURIYAN, A., WINKLER, J., DEVARAJAN, P., RAMAMOORTHY, S.K., JAKIMIUK, A., OSINSKI, P., PODLASEK, A. and VAVERKOVÁ, M.D., 2023. Advancements in Solar Panel Technology in Civil Engineering for Revolutionizing Renewable Energy Solutions—A Review. Energies, 16(18), pp. 6579.

[22] ADEBISI, J., IBILI, P., EMEZIRINWUNE, M. and ABDULSALAM, K., 2023. Comparative Study of Hybrid Solar Photovoltaic - Diesel Power Supply System. African Journal of Inter/Multidisciplinary Studies, 5(1), pp. 1-15.

[23] ADEFARATI, T., OBIKOYA, G.D., SHARMA, G., ONAOLAPO, A.K. and AKINDEJI, K.T., 2024. Design and feasibility analysis of grid-connected hybrid renewable energy system: perspective of commercial buildings. Energy Systems, 15(1), pp. 403-462.

Received: July 24, 2025 

**International Journal of Applied Mathematics**

**Volume 38 No. 1s, 2025**

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

[24] AFSHARI, H., HUSEV, O., MATIUSHKIN, O. and VINNIKOV, D., 2022. A Review of Hybrid Converter Topologies. Energies, 15(24), pp. 9341.

[25] ALGHAMDI, H. and ALVIZ-MEZA, A., 2023. Techno-Environmental Evaluation and Optimization of a Hybrid System: Application of Numerical Simulation and Gray Wolf Algorithm in Saudi Arabia. Sustainability, 15(18), pp. 13284.

[26] AMIT, K.P., SAYMA, A.S., ISLAM, S., MALVONI, M., JAYAKUMAR, A., DEB, S. and NALLAPANENI, M.K., 2022. Feasibility Assessment of Hybrid Solar Photovoltaic-Biogas Generator Based Charging Station: A Case of Easy Bike and Auto Rickshaw Scenario in a Developing Nation. Sustainability, 14(1), pp. 166.

[27] BHANJA, A., KUMAR, A. and GUPTA, A., 2021. TECHNO-ECONOMIC CHALLENGES IN IMPLEMENTATION OF SOLAR EQUIPMENT BASED ON A STAND-ALONE MICROGRID IN HILLY TERRAINS OF RURAL INDIA. Acta Technica Corviniensis - Bulletin of Engineering, 14(2), pp. 95-104.

[28] CABRERA-TOBAR, A., GRIMACCIA, F. and LEVA, S., 2023. Energy Resilience in Telecommunication Networks: A Comprehensive Review of Strategies and Challenges. Energies, 16(18), pp. 6633.

[29] CHOU, J. and MOLLA, A., 2022. Recent advances in use of bio-inspired jellyfish search algorithm for solving optimization problems. Scientific Reports (Nature Publisher Group), 12(1),.

[30] DEEVELA, N.R., KANDPAL, T.C. and SINGH, B., 2024. A review of renewable energy based power supply options for telecom towers. Environment, Development and Sustainability, 26(2), pp. 2897-2964.

Received: July 24, 2025