

A Comprehensive Review of Stand-Alone Hybrid Microgrid Systems for Agricultural Irrigation Using Solar and Diesel Energy

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Abstract

Farmers have increased their dependence on diesel generators because agricultural irrigation requirements have experienced rapid growth which results in them suffering from high diesel expenses and fuel shortages and environmental destruction. Microgrids which implement hybrid renewable energy systems provide a sustainable method to fulfill electricity requirements. The review paper examines all current research findings about agricultural and rural irrigation applications of solar photovoltaic PV diesel battery hybrid microgrid systems. The review presents microgrid system designs which include component integration methods and energy management solutions and recent literature-based optimization methods. The research focuses on three main areas which include Maximum Power Point Tracking MPPT technology and battery energy storage systems and advanced energy management systems that achieve two objectives which are decreasing diesel fuel usage and bolstering system reliability. The research evaluates both techno-economic and environmental dimensions through lifecycle costing and renewable energy adoption and greenhouse gas emission decrease. The research demonstrates that real-world challenges arise from intermittent power sources and system capacity requirements and complex control systems and sustainable operational demands. The study uses literature assessments to define research deficiencies which help researchers create hybrid microgrids that meet sustainable agricultural irrigation needs and rural energy needs while being efficient and affordable and expandable.

Keywords: Hybrid Microgrid, Solar Photovoltaic (PV), Diesel Generator, Agricultural Irrigation, Energy Management System etc.

1. Introduction

Developing countries and rural areas depend on diesel generators to fulfill their irrigation power needs because these regions lack reliable access to electricity grids. Diesel generators enable operations to run smoothly while providing dependable power sources but their widespread usage drives up fuel expenses while generating more greenhouse gases and harming the environment [1]. Agricultural operations need cleaner energy solutions because rising fuel costs and climate change concerns create urgent demand for sustainable energy options.

The implementation of solar photovoltaic (PV) systems has increased in popularity because they deliver renewable energy which has become less expensive and benefits environmental protection. Most agricultural regions receive sufficient solar energy which matches their irrigation needs during the day [2]. The sunlight that PV systems capture converts into electrical power which helps decrease the need for fossil fuel resources. Solar energy production follows natural patterns which develop through daily sun cycles and weather changes and seasonal variations. This pattern makes it impossible to generate constant power for irrigation needs from solar energy when it functions as the only energy source [3].

The combination of solar PV with diesel generators and battery energy storage systems creates hybrid energy systems which successfully solve these challenges. The system design of hybrid microgrids establishes dependable systems that operate with maximum efficiency through the integration of renewable and conventional energy sources. The solar photovoltaic system functions as the main power source in these systems, while diesel generators provide emergency

power during periods of low solar energy or when demand reaches its highest point. The system uses battery storage to enhance performance through two functions: it regulates power fluctuations and it stores excess solar energy for later use during nighttime and cloudy periods [5].

Microgrids function as local energy systems which can operate either as part of a grid or independently without it. The rural agricultural areas which lack access to electrical grids function as ideal environments for establishing stand-alone microgrids which provide dedicated power supply [6]. Research shows that PV-diesel-battery hybrid microgrids reduce both diesel fuel usage and operational expenses while decreasing carbon emissions when compared to systems which use only diesel power [7]. The development of power electronics together with control algorithms and energy management systems has achieved system stability enhancements that result in increased operational efficiency and greater system capacity for expansion.

Hybrid microgrid systems get their highest operational performance through the essential support that energy management systems (EMS) provide. Intelligent EMS systems use renewable energy resources as their main focus while they control battery operations and diesel generator scheduling to minimize fuel consumption and equipment maintenance requirements [8]. The Maximum Power Point Tracking (MPPT) technique enables PV panels to achieve their highest energy output under different environmental conditions which results in better overall system efficiency [9]. The evaluation of techno-economic feasibility and optimal system sizing requires simulation platforms and optimization tools which use both HOMER and MATLAB-based models for their assessment [10].

The hybrid microgrid research field has produced multiple studies but the research area still needs to overcome several existing obstacles. The research needs to solve the problems which include accurate load forecasting for irrigation systems and understanding long-term battery degradation and managing control system complexity and developing site-specific design requirements [11]. Most studies investigate either generic rural electrification systems or island systems while they fail to examine the specific agricultural load patterns and operational restrictions which farmers need to operate their businesses [12]. The agricultural sector requires hybrid microgrids which need to solve these existing gaps.

The review paper combines recent research studies about solar photovoltaic diesel battery hybrid microgrid systems which agricultural irrigation. The research study investigates all system components through its architectural design and control mechanisms together with techno-economic evaluations and environmental assessments in order to present a complete picture of existing research patterns while showing what sustainable agricultural energy systems will develop in the future.

2. Problem Identification

The electrical grid connections of diesel generators which agricultural irrigation systems in rural and remote areas depend on experience major operational issues. Diesel-operated irrigation systems create high operational and maintenance costs which include unpredictable fuel delivery expenses plus they generate substantial greenhouse gas emissions that harm environmental protection efforts while reducing farmers' profit potential [1]. The solar photovoltaic (PV) energy system which provides abundant clean power faces environmental challenges because its daytime operation depends on continuous power supply which alters during nighttime and weather and seasonal changes [2]. The system efficiency and reliability decrease because the system lacks essential energy storage elements and advanced control technologies [3]. The existing power solutions currently available do not support agricultural operations because they fail to account for the specific energy needs of farming activities and the extended operational times needed for irrigation pumps [4]. Agricultural irrigation systems require an energy solution which delivers reliable performance through a hybrid microgrid system that uses renewable energy and traditional backup systems to provide affordable renewable energy [5].

3. Literature Survey

A) Literature Review

Q. Hassan et al. (2023), The paper presents a comprehensive examination of hybrid solar-wind energy systems through its analysis of their operational structures and energy requirements and their methods for managing energy distribution. The study demonstrates that hybrid systems reduce power supply interruptions while enhancing system performance because storage systems are incorporated into the hybrid design. The review assesses different optimization techniques which include genetic algorithms and PSO and determines that storage systems are essential for achieving peak power reduction and system dependability. The analysis of techno-economic trade-offs shows that increased renewable energy usage results in decreased fuel costs and operational maintenance expenses but leads to higher initial capital expenses and operational difficulties. The authors emphasize that site-specific performance assessment needs to consider climatic conditions and resource availability and load patterns because these factors determine the best system design and they propose that unified policy systems with financial incentives should be established to improve deployment in rural and island areas.

M. Uddin et al. (2023), The paper presents a detailed analysis of microgrid concepts together with their AC and DC and hybrid system types and their primary to tertiary control systems. The main technical challenges which were recognized by the study include sustaining system stability during high distributed energy resource implementation and achieving proper protection coordination and maintaining power quality and developing blackstart operational capability. The review emphasizes the requirement for communication systems and cybersecurity measures to support advanced energy management systems while showing the need for standardized systems to achieve successful interoperability. The study identifies economic and regulatory obstacles which include tariff structures and interconnection rules as primary non-technical obstacles that hinder progress. The recommended future research directions start with developing scalable control systems for networks which depend on distributed energy resources and continue with creating secure protection systems for independent operation and conducting socio-technical research on how rural areas adopt new technologies. The researchers and policymakers receive practical guidelines which support their work.

J. Lata-García et al. (2024), this paper describes how a case study was conducted to improve the efficiency of a hybrid system that includes photovoltaic technology, biomass energy, diesel generators, and battery storage systems to serve an island community. The research team used simulation and optimization tools (HOMER and other tools) to show that mixed renewable energy systems can achieve reliability targets with lower total life cycle expenses than diesel-powered systems. The optimized solution achieved a diesel runtime reduction while sustaining load capacity and maintaining a low probability of power outages. The study shows that component cost, fuel price, and resource availability changes can create threshold points which make additional photovoltaic systems and storage solutions financially beneficial. The research demonstrates that local resource evaluation together with multi-objective optimization which includes cost, emissions, and reliability assessment needs to work together for successful rural project execution.

D. Yamegueu et al. (2024), The research paper examines how operational PV-diesel microgrids function in African rural areas, studying the impact of customized energy management systems and dispatch methods on fuel use and solar energy integration. The research demonstrates that advanced dispatch systems combined with load scheduling methods, which include peak shifting and load prioritization, can achieve substantial reductions in diesel engine operational time. The implementation of correctly optimized energy management systems enhances both renewable energy utilization and financial performance when battery systems are present. The research team identifies three main operational limitations which include maintenance capacity and fuel logistics and user behavior because these socio-technical elements have a stronger impact on achieving long-term objectives than technical and economic performance indicators. The team proposes that communities should receive training while their energy management systems should function better through short-term forecasting integration.

W. Wang et al. (2025), this research uses HOMER and lifecycle costing to evaluate PV-diesel-battery hybrid systems which provide power to agricultural and poultry farm operations. The case studies assess grid-tied systems and off-grid systems under different tariff and incentive conditions. The results demonstrate that integrating PV systems with battery

storage decreases diesel-only system costs which measure LCOE together with diesel usage and CO₂ emissions in locations with strong solar resources and high fuel prices. The sensitivity analysis results show that battery costs and fuel prices represent the main factors which determine whether the project will be economically viable. The operational strategies which maximize daytime solar energy use while preventing excessive battery cycling will extend system lifespan and enhance economic performance. The paper provides practical sizing guidance for farm-scale deployments.

R. G. Mohamed et al. (2025), The paper presents advanced EMS system which integrates predictive PV forecasting with an Artificial Protozoa Optimizer to determine dispatch decisions. The PV–DG–battery microgrid simulation demonstrates that the strategy decreases diesel engine operation time and fuel usage when compared to standard rule-based controllers while achieving higher PV system performance. The controller uses short-term irradiance forecasts together with load predictions to create an optimal schedule for battery charging and discharging activities and for starting and stopping DG operations. The study shows that predictive EMS systems reduce operational expenses and environmental emissions but their effectiveness depends on the accuracy of weather predictions and the available computing power. The study shows that hybrid methods which combine forecasting with optimization and basic heuristic techniques create effective field-tested EMS systems.

J. C. León Gómez (2023), this paper on HRES architectures and battery technologies. The review evaluates two different power distribution systems which include centralized systems and distributed systems. The research examines various battery energy storage system chemistries and their operational lifespan challenges while reviewing methods to determine system size requirements through both single and multiple objectives. The research identifies an increasing pattern which designers use to incorporate demand-side management systems together with Internet of Things-based monitoring technologies into their latest projects. The research demonstrates that three elements which include battery techno-economics lead to system design decisions while three elements which include CAPEX and reliability and emissions require multi-objective optimization to achieve balance. The paper demands that researchers conduct additional real-world testing to confirm model assumptions which will improve the understanding of long-term BESS performance in hybrid dispatch systems.

S. Jamal et al. (2024), This paper presents a rule-based Emergency Management System which controls photovoltaic battery hybrid systems through a genetic algorithm that optimizes key cost and battery lifespan threshold parameters. The method maintains rule-based dispatch system efficiency for field sites with limited resources because of its simple and strong performance characteristics but achieves better results through GA-based parameter tuning. The simulation results demonstrate better cost performance and less battery cycling damage when compared to rules that were not optimized. The authors present simple controller evolutionary tuning as a solution which enables rural microgrids to use basic control systems because they need operational systems that require less computational power.

A. S. Aziz et al. (2022), The authors of this research document present their hybrid optimization solution for off-grid systems which incorporates a 12-hour dispatch model into HOMER for a rural Iraqi community. The model shows that using foresight for dispatching results in lower fuel consumption and better economic performance than the standard charging methods used in cycle-charging operations. The system achieves operational efficiency through its optimized design which determines the necessary photovoltaic capacity and battery storage requirements needed to achieve reliable performance at the lowest net present value. They demonstrate that design choices depend on two main factors which include actual fuel costs and solar power fluctuations and they suggest diesel usage reduction through operational forecasting and demand prediction methods which should be used in real-world operations. The study provides dispatch instructions and equipment size recommendations which help operate in extreme desert environments.

M. A. Omar (2024), The study explores financial models and investment frameworks which corporate entities use to implement rural microgrid systems through their corporate-led projects. The research demonstrates that corporate financing methods which include lease and PPA and ESCO financing options enable companies to overcome their initial capital expenditure challenges. The paper demonstrates through its case modeling research that blended finance solutions shorten payback times while corporate participation helps companies achieve lower costs through bulk purchasing and service upkeep. The achievement of objectives requires consistent governmental regulations combined with fair fuel

costs and open revenue distribution systems which smallholder farmers can access. The research recommends establishing public–private partnerships together with customized financial solutions to enable expansion of hybrid microgrid systems at agricultural operations which will enhance energy access while generating higher financial returns for investors.

M. Bilal et al. (2025), this paper introduce a Hybrid Particle-Whale Optimization Algorithm (HPWOA) for sizing standalone microgrids combining PV, wind, DG, and BESS. The hybrid metaheuristic addresses convergence limits of single-method optimizers and yields balanced solutions minimizing cost and emissions while meeting reliability metrics. The case studies demonstrate that HPWOA achieves better results than traditional PSO and WOA methods because it discovers less expensive system designs which maintain identical reliability standards. The research shows that hybrid optimization techniques can successfully handle multi-modal search problems which arise in multi-technology microgrid sizing although their computational demands and parameter adjustment needs restrict their practical application.

T. Michael et al. (2025), the research paper conducts a systematic examination of PV-battery-DG systems which provide electricity to remote islands. The research shows that optimal design solutions depend on three factors which include the size of the island and its fuel supply system and its electricity consumption patterns. The review emphasizes that local capacity development is essential for sustained operational needs while recommending a combination of technical optimization and community training with maintenance planning. The policy recommendations propose specific subsidies for storage systems and local operations and maintenance training programs which will enhance sustainability in hybrid systems used on islands and in rural areas.

B) Literature Summary

Recent studies on hybrid renewable energy systems highlight the growing importance of solar photovoltaic (PV)–diesel–battery microgrids for reliable power supply in rural and agricultural applications. The literature confirms that integrating PV with diesel generators shows fuel savings and lower operational costs and reduced carbon emissions while maintaining supply reliability during low solar availability [1]–[3]. Battery energy storage systems function as essential components for solar energy storage since they enable continuous solar power supply and keep power systems operating smoothly [4]. Advanced energy management systems (EMS) and MPPT techniques and HOMER optimization tools together create a comprehensive system which developers use to improve both renewable energy usage and economic performance [5]–[7]. Several review and case studies demonstrate the feasibility of hybrid microgrids for rural electrification and isolated communities [8]–[10]. The majority of research studies use generic load profiles to study island electrification but they do not consider agricultural irrigation needs or the actual challenges faced during operations [11], [12].

C) Research Gap

- The research studies which exist about irrigation load patterns only include a few studies which examine how farmers irrigate their fields during different seasons and when they use their irrigation systems for long periods.
- The current research does not explore how energy management systems developed for real-time energy control of irrigation pump systems function.
- The researchers have not completed an in-depth study which examines how dust and shading together with other environmental factors impact photovoltaic systems in agricultural environments.
- Only a few studies have tested irrigation systems which use MPPT-controlled photovoltaic systems together with battery storage and diesel generators within one control system.
- Research on battery performance decline together with maintenance expenses for hybrid agricultural microgrids has not advanced beyond studies which examine their performance in short time periods.
- The researchers have conducted only a small amount of research about self-sufficient microgrid systems which provide power to remote agricultural communities that lack regular electricity service.
- The current research does not provide effective methods which evaluate how agricultural energy systems impact the environment and their sustainability performance.

- Rural agricultural areas need hybrid microgrid solutions which enable them to grow their operations while providing cost-effective electricity for their agricultural work.

4. Research Methodology

A) Criteria for selecting this study:

Urgent energy requirements exist within the agricultural irrigation sector because rural areas lack access to grid electricity. The system requires diesel generators to operate which results in higher operational expenses and equipment breakdowns and releases harmful substances into the environment. Agricultural areas possess abundant solar energy resources which make solar photovoltaic systems suitable for use as their main power source. The agricultural sector requires continuous power supply which establishes the foundation for their irrigation systems and enhances their crop yield performance. Solar power systems face operational restrictions because their electricity production depends on weather conditions. Hybrid microgrid systems demonstrate their capacity to combine renewable energy sources with conventional power generation methods. The agricultural sector demonstrates a strong trend to adopt environmentally friendly farming practices that protect natural resources. The sector currently offers advanced power electronics together with maximum power point tracking systems and complete energy management solutions. The agricultural sector creates opportunities to decrease greenhouse gas emissions while achieving energy self-sufficiency. The study demonstrates its importance to achieve rural development goals while supporting energy security projects.

B) Method of analysis:

The researchers conducted their research by studying all existing studies which focused on solar photovoltaic diesel battery hybrid microgrid systems. The team assessed irrigation load needs by evaluating both power requirements and pump usage times. The researchers developed a hybrid microgrid system model which included all system elements including PV panels diesel generators and battery storage and converters. The researchers applied MPPT algorithms to enhance solar energy extraction from photovoltaic systems. The researchers created an advanced energy management system which enables effective power distribution among photovoltaic systems and battery storage and diesel generators. The system performance assessment used simulation methods to test different solar irradiation levels and load variation scenarios. The study measured three outcomes which included energy efficiency and fuel savings and emission reduction effectiveness. The study used a techno-economic evaluation method to assess operational expenses and sustainable development.

C) Comparison and Analysis:

Table 1. Comparison and Analysis of Literature parameters.

Author / Year	Hybrid System Configuration	Control / EMS Strategy	Energy Storage Integration	Application Focus
Hassan et al., 2023	Solar–Wind–Battery–DG hybrid	Optimization-based sizing and control	Battery emphasized for reliability	Rural and off-grid power systems
Uddin et al., 2023	Multiple microgrid architectures	Hierarchical microgrid control	Considered as support system	General microgrid applications
Lata-García et al., 2024	PV–Biomass–DG–Battery	Techno-economic optimization	Battery essential for continuity	Rural electrification
Yamegueu et al., 2024	PV–DG microgrid	Energy Management Strategy (EMS)	Optional / limited battery use	Rural African microgrids
Wang et al., 2025	PV–DG–Battery	HOMER-based dispatch strategy	Strong battery dependency	Agricultural and farm loads
Mohamed et al., 2025	PV–DG–Battery	Predictive EMS with forecasting	Integrated for optimization	Stand-alone microgrids
Michael et al., 2025	PV–Battery–DG	Optimization and policy analysis	Battery critical for reliability	Island electrification

Review Studies	Multiple hybrid configurations	Rule-based and intelligent control	Widely recommended	Rural and renewable integration
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Key Observations :

- The majority of research studies prove that battery storage functions as an essential element which maintains system reliability.
- The implementation of energy management strategies produces a major impact on the amount of diesel fuel that gets reduced.
- The field of agricultural irrigation research needs more exploration than the established studies about rural electrification.
- Only a small number of research studies examine how irrigation systems experience changes in their water demand throughout different times during the day.

D) Evaluation of methodologies used in the reviewed studies

Different research studies use various methods to study hybrid microgrid systems. The majority of research studies use simulation-based modeling which employs MATLAB/Simulink and optimization algorithms to test system performance under different load and resource conditions [1], [3], [5]. Techno-economic analysis serves as a common methodology which assesses the complete operational expenses and fuel savings together with the functional performance of hybrid systems throughout their entire lifespan [4], [7]. Researchers use energy management systems which include three types of controllers to reduce diesel consumption while increasing renewable energy use [6], [8]. The implementation of MPPT systems enables PV technology to achieve optimal performance during changes in environmental conditions [9]. Theoretical simulations represent the research boundary for many studies because only a few studies test their findings through actual experiments or extended field testing [10], [11]. Researchers have to create operational agricultural hybrid microgrid systems which require complete testing and verification procedures for their research work.

E) Highlighting trends, advancements, and challenges

Trends :

- Rural agricultural operations are increasingly adopting solar PV-diesel-battery hybrid microgrids for their operational needs.
- Energy management systems now use renewable resources as their main energy source instead of diesel power systems.
- Designing systems requires optimization and simulation tools which include HOMER and MATLAB.
- The solution to intermittent solar energy production problems can be achieved through battery energy storage systems that operate alongside solar power.
- Stand-alone microgrids provide independent power systems which remote irrigation systems and off-grid farming areas need to operate.
- Current agricultural energy systems focus on sustainability practices to achieve lower emission levels.

Advancements :

- The intelligent energy management systems development process requires both predictive and optimization control methods for their operational control.
- The new MPPT algorithms achieve better solar energy conversion results because they work effectively in changing environmental conditions.
- The development of new battery technology enables storage systems to achieve higher energy capacity and extended operational lifespan.
- The upgraded power electronic converters result in better system performance and improved power delivery to consumers.
- Organizations use IoT technology together with continuous monitoring systems to track their system performance while detecting equipment failures.

- The combination of control methods enables substantial reductions in both diesel engine operation time and diesel fuel consumption.

Challenges :

- The solar energy system experiences intermittent power generation which leads to reliability problems when there is no appropriate storage solution.
- The photovoltaic and battery system costs represent a significant financial burden that small-scale farmers must pay.
- Batteries face performance decline and require upkeep throughout their extended operational life.
- Existing research only investigates load fluctuations that are specific to agricultural operations.
- The protection and control systems used in stand-alone microgrids create operational difficulties.
- The absence of practical testing combined with the missing long-term operational research results in a research gap.

5. Discussion

A) Synthesis of findings from literature

The research evidence demonstrates that hybrid microgrid systems which combine solar photovoltaic systems with diesel generators and battery storage systems create a dependable energy solution which meets the requirements of rural and agricultural energy needs. The majority of research studies established that choosing solar energy as the main energy source leads to lower diesel fuel usage and reduced operational expenses and greenhouse gas emissions while enhancing energy security [1]–[3]. The research study established that battery energy storage systems function as critical elements which enable solar power systems to supply continuous power to their customers [4][5]. Advanced energy management methods which establish MPPT-based control and predictive dispatching techniques lead to improved system efficiency and higher renewable energy implementation [6][7]. The simulation-based techno-economic analysis shows that hybrid systems achieve better life cycle cost performance than diesel-only systems [8]. Existing research demonstrates that agricultural load requirements necessitate the development of hybrid microgrid systems which irrigation systems need because researchers lack both practical testing capabilities and studies about agricultural load requirements [9][10].

B) Methodology for future research directions

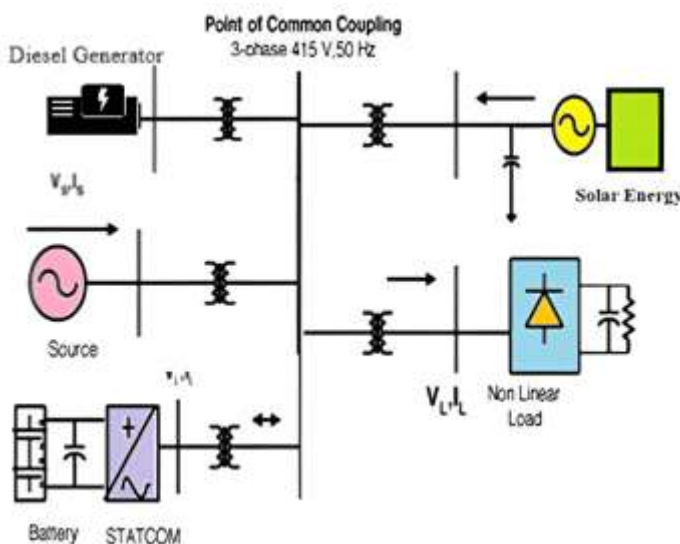


Fig.1. Grid Connected Solar and DG generator System

The static synchronous compensation system operates as a regulated voltage source inverter (VSI) which supplies electrical power to the grid. The system maintains supply current in accordance with designated phase-angle values which it achieves by balancing supply current with actual voltage supply. The inverter produces reactive current which generates electrical power to eliminate both the inductive generator and non-linear load induced reactive current and harmonic distortion. The process improves electricity quality through power factor enhancement. The electrical converter generates its current command through a process which involves subtracting the synchronized grid voltage from the electrical system. The grid connection methods at the point common coupling (PCC) base power quality improvements have been reversed. The grid-connected system displays an example of its functioning operation.

The project implements DG generator together with PV solar panels for irrigation systems which support agricultural activities. The solar panels generate electrical power which the charging controller distributes to users. The charging control system supplies power to operate the solar tracking system. The solar tracking device enables accurate sun-based solar panel alignment. The system uses its leftover energy to operate devices and charge batteries. The system requires battery backup to provide power during nighttime hours. The DC electrical supply system transmits power through DC distribution cables which connect to DCDB (DC Distribution Box) for further distribution. The boost converter enables us to extend our transmission range for longer distances. The microgrid network can be disabled through a single button which activates fault protection measures. The microgrid network extends its coverage area by repeating its operational process.

The proposed hybrid microgrid system for agricultural irrigation uses solar photovoltaic (PV) panels and battery energy storage and diesel generator to produce continuous power supply. Solar PV panels act as the primary energy source which converts sunlight into electricity during daytime. The system uses a charge controller with Maximum Power Point Tracking (MPPT) to manage DC power distribution which optimizes power extraction from solar energy sources under different weather conditions. The regulated energy supply system directly powers irrigation pumps while also charging the battery storage system.

The battery delivers emergency power support for both night hours and times when solar power is insufficient which allows irrigation systems to work without interruption. The diesel generator activates automatically to deliver essential electricity when both solar panels and battery storage fail to supply enough power to sustain operational needs thus ensuring system dependability. The intelligent microgrid control unit tracks power consumption and battery capacity and solar energy production to control power distribution from different energy sources. The control system achieves renewable energy power usage as its first goal while it decreases diesel engine operation time and fuel needs and it boosts the total performance and ecological sustainability of the system.

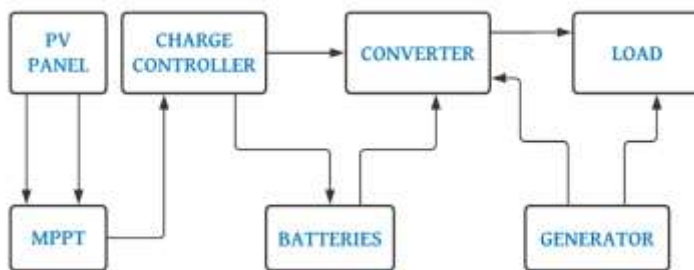


Fig. 2: Representation of Hybrid Solar PV- Diesel System

The researchers developed a hybrid microgrid system which they used to design and evaluate agricultural irrigation systems through MATLAB/Simulink testing. The MATLAB environment enables users to build exact mathematical models that describe system parts which comprise solar photovoltaic (PV) arrays and diesel generators and battery energy storage systems and DC-DC converters and inverters and irrigation pump loads. The simulation framework enables accurate evaluation of system performance under different solar irradiance conditions and temperature changes and load demand variations and agricultural irrigation operating conditions.

The research team used MATLAB to implement control strategies which included Maximum Power Point Tracking (MPPT) for PV systems and intelligent energy management algorithms to achieve optimal power generation and efficient energy source usage. The battery model enables users to investigate how state of charge (SOC) charging and discharging patterns operate during nighttime or low solar conditions. The diesel generator model provides power to meet electricity needs during peak irrigation periods when renewable energy sources cannot supply enough power.

Users of MATLAB/Simulink can assess different operational scenarios which evaluate both off-grid and grid-based irrigation systems. The schematic model demonstrates the interconnected operation of all subsystems which together form a complete system of hybrid microgrid technology used in agricultural irrigation.

6. Conclusion

The review conducted an in-depth investigation of current studies about hybrid microgrid systems which combine solar photovoltaic (PV) energy with diesel generators and battery storage systems by focusing on their use in agricultural irrigation. The literature demonstrates that hybrid microgrids provide a dependable and environmentally friendly

solution which replaces traditional diesel power systems in rural areas that lack access to electrical grids. The primary energy source for solar photovoltaic systems has become diesel generators because of their widespread availability and decreasing operational costs but diesel generators function as power backup systems which ensure continuous electricity delivery during times when renewable energy sources are not available. The battery energy storage systems function as essential components which help to manage solar power fluctuations while they improve system reliability and increase operational efficiency. The development of energy management systems together with new MPPT methods and optimization software solutions has enabled renewable energy systems to operate more efficiently while decreasing their need for fossil fuels and greenhouse gas emissions. The review identifies ongoing problems which include two separate issues from high startup expense to battery performance decline and difficulties in system management and battery testing in actual conditions. The research needs to develop agriculture-based load modeling methods together with field research and inexpensive hybrid microgrid systems to help scientists develop sustainable agricultural irrigation systems.

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