

**A STUDY OF RENEWABLE ENERGY RESOURCES AND ITS APPLICATION IN
REMOTE AREAS OF ARUNACHAL PRADESH -INDIA**

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Abstract

This research work explores the techno-economic feasibility of solar-powered, IoT-integrated water pump systems in rural Arunachal Pradesh, with a particular focus on their enhanced monitoring and control capabilities. The proposed solution integrates solar photovoltaic (PV) systems with grid-powered induction motors to improve the efficiency of water pumping operations. HOMER Pro is employed to design and analyze renewable energy systems, assessing their feasibility in specific regions of Arunachal Pradesh—Likor village being selected as a representative case study. The research underscores the importance of sustainable water solutions in remote and challenging environments, addressing the critical need for environmentally friendly and cost-effective on-grid and off-grid alternatives based on location. MATLAB simulations are conducted to model the Solar PV and Grid-Driven Induction Motor configuration for water pumping applications. A key component of the study is the integration of IoT-based monitoring systems, which significantly enhance the system's functionality through real-time data and control features. The study aims to compare the techno-economic viability of these smart solar-powered water systems, offering a thorough analysis of their feasibility, cost-effectiveness, and operational efficiency. Ultimately, the research demonstrates the practical applicability of renewable energy technologies in remote rural settings.

Keywords: Remote area energy generation, Hilli terrain transmission, Homer Pro, Powerplant design, Micro-hydro generation

1. Introduction

In this section a thorough literature survey is being conducted on the technologies that are developed for small scale uses and which is also compatible to remote areas. The research delves in [3] is into enhancing solar photovoltaic power generation through IoT-based automation. It focuses on improving efficiency, control, and maintenance, including cleaning the photovoltaic array, using an integrated system involving Raspberry Pi as a processor and IoT communication via its built-in Wi-Fi module. With the addition of an Arduino Uno microcontroller assembly tracking the sun's position for optimal energy collection, the system

aims to elevate performance, fault detection, and real-time monitoring in solar power generation. Successfully implemented, this system streamlines plant management, providing constant updates on plant output and reducing manual intervention for maintenance. The smart solar PV setup not only minimizes operational time but also maximizes electricity generation by precisely capturing solar radiation [3].

A comprehensive analysis explores the domain of Solar Photovoltaic (PV) powered water pumping systems, with a specific focus on their integration with Brushless DC (BLDC) motors. Solar-driven systems are gaining traction due to their environmentally friendly characteristics and elimination of fuel expenses, particularly in sectors like agriculture and industry where conventional electric or diesel pumps encounter reliability issues and rising fuel costs. The objective of the study is to provide an extensive literature review highlighting the advantages of BLDC motors compared to DC and AC Induction Motors in water pumping applications. It addresses various system components such as PV arrays, maximum power point tracking control systems, and motor-pump configurations. While PV-based water pumping is lauded for its environmental benefits, the analysis acknowledges the technology's limitations due to high installation costs, particularly for large-scale irrigation and water supply systems. It suggests the necessity for governmental incentives to bolster its attractiveness relative to traditional diesel and electric alternatives.[4].

Examines direct-coupled photovoltaic water pump systems (PVWPS), delving into their performance and assessing a weathered solar pump in a Himalayan Indian region. The analysis homes in on PVWPS efficiency, size optimization, and the integration of electronic controls, particularly highlighting the positive impact of intellectual control methods like maximum power point tracking (MPPT) in varied outdoor conditions. Techno-economic evaluations showcase the cost-effectiveness of PV-integration of water pumping over diesel-powered systems. The case study underscores the resilience of an aging DC solar pump despite significant module degradation, emphasizing the importance of ongoing monitoring and adaptations for prolonged usage. Overall, this comprehensive review underscores the adaptability of these systems for small-scale needs and urges advancements in controls and monitoring for broader applications, stressing the significance of continual research and improvements for long-term effectiveness in addressing water supply challenges[5].

Explores the application of MATLAB/Simulink for the analysis of a solar-PV water pumping system (PWPS). The system integrates a permanent magnet DC motor driving a centrifugal pump, regulated by a perturb and observe (P&O) maximum power point tracking (MPPT) algorithm. Through simulation, conducted under various conditions including standard test, fluctuating solar irradiance, and partial shading, distinct system responses were observed. Under standard conditions, the PV array generated 1200 W, resulting in a motor speed of 2717 rpm and a water discharge of 4.135 L/s. However, when subjected to varying solar radiation, the discharge decreased to 1.605 L/s due to the fluctuating irradiance.

Notably, under partial shading, the P&O MPPT technique inaccurately identified the maximum power point, mistaking a local maximum for the global maximum power point (GMPP) [6].

Discusses the extensive research and development over more than five decades, the domain of Solar Photovoltaic Water Pumping Systems (SPVWPS). These systems involve various engineering aspects, blending based engineering research. Research in this area has been interdisciplinary, drawing contributions from different engineering domains to enhance efficiency and cost-effectiveness for human, livestock, and irrigation water needs. The review aims to comprehensively cover SPVWPS literature from 1975 to 2014, focusing on its classification, historical background, and ongoing research. Specific attention is given to the Maximum Power Point Tracking (MPPT) system, pump and motor types, and PV panel ratings, crucial factors influencing system performance and economics. The review incorporates research from global perspectives, encompassing experimental, theoretical, and mathematical modelling studies. It underlines the potential of SPVWPS in supplying water for drinking and irrigation, especially in developing nations. The paper emphasizes the need for further research in this area, presenting opportunities for future studies. In the Indian context, despite its geographical advantages, SPVWPS has not gained widespread acceptance due to cost and sustainability concerns. The authors address this by designing a test facility in Nagpur, India, focusing on developing reduced cost based solar operated submarine water pumps for individual households and small farmland irrigation. Their work to investigate the techno-economic feasibility of such systems in this region [7].

The reliance on diesel-powered pumps for irrigation faces multiple challenges, including rising oil costs, emissions, maintenance expenses, and short operational lifespans. Consequently, a shift towards solar-powered water pumping systems has gained traction due to their superior reliability, eco-friendliness, and cost-effectiveness compared to diesel counterparts. This review offers a concise examination of solar photovoltaic (PV) water pumps, emphasizing their components, applications, and particular relevance in India. Highlighting their economic viability and environmental benefits, the solar PV pumps exhibit cost-effectiveness, reliability, and reduced environmental impact. Additionally, the discussion delves into government initiatives, subsidies, and schemes designed to incentivize the adoption of solar liquid pumping systems. In conclusion, these systems emerge as eco-friendly alternatives, supported by government programs, and prove especially beneficial for cooling, industrial, Agri and so on water supplies in regions blessed with ample sunlight [8].

Explores the viability of solar photovoltaic (PV) and wind energies for water pumping applications, emphasizing their efficiency and suitability, particularly in remote areas devoid of traditional power sources. Effective control strategies are essential for optimizing these systems, ensuring safe and efficient operations by monitoring parameters such as voltage, flow, torque, and motor performance. The review examines research on control techniques applied to solar PV and wind-powered water pumping systems, with a focus on the significance of Maximum Power Point Tracking (MPPT) for enhancing efficiency and performance across varying climatic conditions. Intelligent MPPT algorithms are recommended for improved system response. Additionally, the selection of appropriate motors and the implementation of robust controllers play pivotal roles in minimizing power requirements and enhancing system reliability. Energy management techniques further contribute to enhanced operation and

prediction accuracy, ultimately enhancing overall system performance. This review serves as a valuable resource for engineers and researchers seeking to implement effective control and energy management strategies in solar PV and wind-powered water pumping systems.[9].

The research investigates the optimization of a Solar based-powered water pumping system in Kuwait's climate, focusing on components like the PV array, DC motor, and centrifugal pump. A simulation program was developed to assess system performance and economic feasibility, considering various factors like PV array size, orientation, and system characteristics.

Key findings emphasize the reliability of a newly developed motor-pump model, proving its accuracy against manufacturer data and software programs. Tilt angle variations minimally affected performance, while optimizing system parameters significantly improved water demand fulfilment in remote areas. Despite current high PV module costs, the study indicates the viability of effective-designed PV pumping systems in Kuwait's climate, with anticipated future reductions in equipment costs enhancing economic feasibility. The research encourages widespread adoption of solar energy systems for a cleaner environment and better economic prospects [10]. Examines and delves into the limitations of diesel-powered pumps in irrigation due to reliability issues, high costs, and environmental concerns, paving the way for solar-powered systems as a viable alternative.

The review focuses on solar-powered water pumping systems, discussing their advancements, global deployment, economic viability, and environmental impact. It highlights their role in reducing carbon emissions, enhancing grassland growth, and their economic competitiveness compared to other power sources. Ultimately, the paper aims to serve as a comprehensive resource for researchers and engineers exploring the technical and economic feasibility of solar-powered water pumping systems [11].

Discusses the potential of solar energy, particularly solar-PV technology, as a viable and eco-friendly solution for meeting increasing energy demands, especially in off-grid locations. It emphasizes the need for hybrid systems in places with varying solar radiation, highlighting their effectiveness in providing reliable and cost-effective power supply. Solar energy, specifically solar-PV technology, has been affirmed as a practical and cost-effective means of generating power, particularly in off-grid rural areas. It acknowledges the geographical variability in solar energy usage and advocates for hybrid systems combining solar with other sources like wind or diesel to ensure reliable energy supply. The study underscores the effectiveness of both stand-alone solar-PV systems and hybrid systems in providing electrification without imposing high maintenance demands, particularly in rural settings [12].

Investigates the challenges of rural electrification in India, with a particular focus on remote villages like Kadayam, Tamil Nadu, and examines renewable energy (RE) as a viable alternative to conventional grid extension. Utilizing HOMERPro software, the study evaluates a hybrid combination of solar, wind, hydro, and battery as a cost-effective, sustainable, and environmentally friendly solution compared to extending grid lines. The paper underscores the significance of maximizing local energy resources and highlights the superiority of the RE-based system over grid extension in terms of cost-effectiveness and environmental

preservation. Simulation results strongly advocate for the superiority of the mixed renewable energy system, especially the Solar/Wind/Hydro/Battery combination, over grid extension and other RE systems. This hybrid system not only reduces the Cost of Electricity (COE) but also demonstrates zero carbon emissions and reduced Net Present Cost (NPC). It ensures stability in electricity production year-round by leveraging complementary effects from solar, wind, and hydro-power. Overall, the hybrid RE system with energy storage effectively meets load demand, lowers COE and carbon emissions, and offers a highly favourable solution for rural electrification [13].

Forecast and emphasizes the rising importance of solar energy, particularly in countries like India facing energy shortages. It highlights the necessity of accurately predicting solar irradiance to efficiently integrate solar energy into the national power grid. The review examines various models for solar radiation prediction, discussing their applications and relevance, particularly in India's context. It stresses the significance of precise solar radiation measurements for optimal solar infrastructure and outlines the current status of India's utilization of solar energy. The discussion emphasizes the critical role of solar energy in India's energy landscape and the necessity of accurate solar irradiance prediction for effective grid integration. It underlines the challenges posed by variable wind and solar power generation, making forecasting essential for grid management. the implementation of diverse forecasting tools and methods, drawing from successful global practices and advocating for the development of multi-model ensembles for solar power forecasting in different regions of India. Additionally, it emphasizes the importance of infrastructure and forecasting techniques for efficient renewable energy management, suggesting a framework that covers both forecasting techniques and necessary infrastructure [14].

Utilizing high-resolution satellite data, this study identifies solar hotspots across India, revealing that nearly 58% of the nation boasts significant solar power potential, with over 5 kWh/m²/day of annual average Global insolation. It underscores the capacity of these solar hotspots to address India's rising energy needs in a decentralized, efficient, and sustainable manner. The research evaluates solar power technologies such as Solar Photovoltaic (SPV) and Concentrated Solar Power (CSP), addressing their techno-economic challenges and advocating for increased research and development efforts to reduce generation costs and enhance competitiveness against conventional fossil fuel-based options. Moreover, it highlights the emission reduction potential of these solar hotspots and foresees the creation of employment opportunities, particularly at the local level. With ambitious solar missions and evolving policy frameworks, the study envisions India emerging as a global leader in solar power generation, paving the way for a low-carbon economy and positioning the nation as 'Solar India' in the coming years [15].

Implementing an Integrated Renewable Energy System (IRES) for powering unelectrified village clusters in Chamoli district, Uttarakhand, India. It assesses local renewable resources, chooses a wind turbine model, evaluates nine energy combinations via HOMER software, and emphasizes the system's sensitivity to biomass prices. The recommended IRES configuration targets cost-efficiency for rural electrification, providing insights for similar projects sensitive

to biomass pricing fluctuations. The techno-economic feasibility for an Integrated Renewable Energy System in Chamoli, Uttarakhand, involves evaluating renewable resources, wind turbine selection, and analysing various energy combinations through HOMER software. It highlights the system's sensitivity to biomass prices, advocating a cost-effective IRES setup. The research aims to guide rural electrification projects, emphasizing the importance of considering biomass pricing fluctuations for similar implementations [16].

Seven types of lithium-ion batteries to replace old ones in solar home lighting systems. Three NCA, LFP, and LFP/LTO—look promising as they cost the same initially but need fewer replacements, reducing overall costs. The falling prices of lithium-ion tech suggest more cost savings in upcoming Decade or more. Examining seven lithium-ion storage types for solar smart-home, three—NCA, LFP, and LMO/LTO—stand out for similar starting costs but fewer replacements, cutting expenses. Systems needing fewer replacements benefit households without support for these costs. Smaller, cost-effective systems and safer battery types like LMO/LTO could reduce overall expenses. As lithium-ion prices drop, they'll likely offer more cost advantages than old batteries [17].

Integrated Renewable Energy Systems (IRES) for power generation, detailing integration configurations, storage options, sizing methodologies, and energy flow control. It highlights the efficacy of hybrid DC-AC setups, emphasizes suitable storage technologies, and discusses AI techniques for system sizing. The conclusion stresses the necessity for improved battery durability and performance, recommends transient analysis for system stability under standalone conditions, and underscores the ongoing need for further research in IRES to enhance energy storage while maintaining cost-effectiveness and reliability [18].

The feasibility of grid-connected photovoltaic systems for residential households in New Delhi, emphasizing the impact of feed-in tariffs, net metering, and time-of-day tariffs on low and middle slab households. It concludes that grid-connected solar PV systems without battery storage are a viable option for decentralized rooftop applications, the feasibility of PV power systems, highlighting the decreasing cost of energy with increased PV penetration, contradicting conventional wisdom. It emphasizes the benefits of grid-connected PV systems, high utilization rates, reliable power supply, and a trade-off balance in tariff structures. The study underscores the significance of solar energy and suggests its application as a framework for social policies promoting decentralized renewable energy systems [19]. Using renewable energy to power remote telecom, proposing SPV/Wind or SPV/Wind/Battery systems. These solutions prove feasible, emission-free, and cost-effective. Additionally, it highlights the environmental benefits and reduced land use through BTS tower modifications. For SPV/Wind hybrid systems, citing their technical feasibility, environmental friendliness, and cost-effectiveness. The hybrid setup, with its potential to store excess energy, can replace diesel-powered telecom systems, offering advantages like reduced emissions and optimized load satisfaction [20].

The study introduces an IoT-based real-time solar power monitoring system tailored to continuously collect and monitor data from photovoltaic panels and environmental conditions.

The aim is to automate monitoring procedures, thereby saving time and ensuring efficient power output while identifying faults and weather-related issues that impact solar effectiveness. Conventional manual methods, particularly those involving multimeters, prove cumbersome for larger systems, underscoring the proposed system’s user-friendly nature. It comprises a microcontroller (Node MCU), PV panel, sensors (INA219 Current Module, Digital Temperature Sensor, LDR), Battery Charger Module, and battery. Data transmission to the cloud (Thingspeak) via IoT technology and Wi-Fi facilitates remote monitoring. Through a Graphical User Interface, users gain access to current, previous, and average parameters, streamlining fault detection and maintenance tasks. Real-time data collection and analysis enable the prediction of power generation possibilities and income output. By optimizing solar power tracking, maximum output can be attained. Furthermore, the system enhances fault detection capabilities and simplifies system maintenance processes [21].

The study delves into the net economic cost and efficiency of two renewable energy systems tailored for IoT applications. The first system comprises a 3KW solar energy source, while the second system features a 3KW wind turbine energy source. Leveraging the HOMER software program, the analysis utilizes input data derived from the daily loads required for a small house in Tikrit city, Iraq. Results reveal that the net cost of installing the 3KW solar energy system amounts to approximately \$14,792.00, whereas the 3 KW

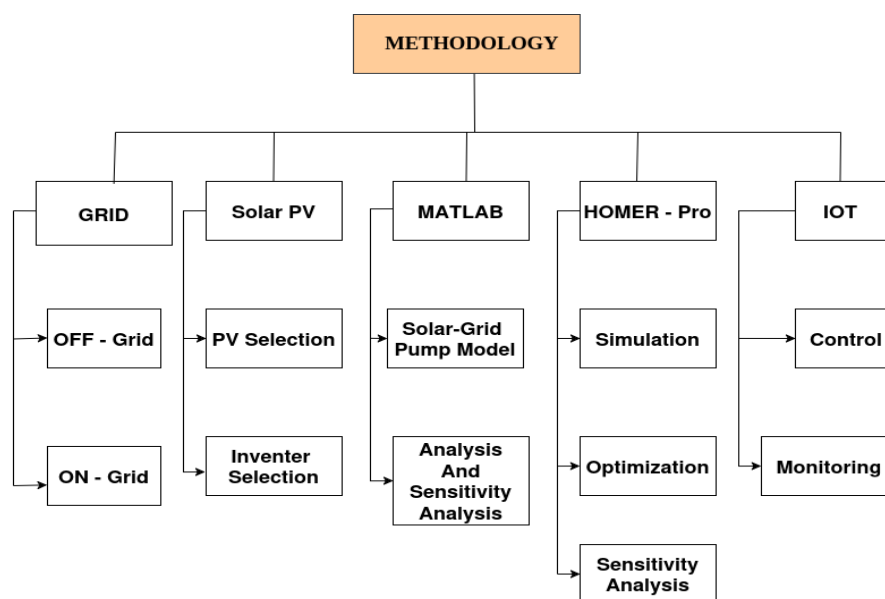


Figure 1: Structure of methodologies used in the plan

turbine system costs approximately \$7,340.00. Despite the wind turbine system’s lower cost, the solar system yields higher electrical power output, rendering it a more viable option for renewable energy sources in the Tikrit region. The study illustrates the performance of these renewable energy systems through figures and tables, representing the quarter-half-yearly mean values of electricity power generation. Ultimately, it underscores the potential of solar

energy systems for electricity generation in regions lacking electrical services, highlighting their suitability for IoT applications.[22]

2. Problem Formulation

2.1 Methodology

The fig. 1 representation of the methodology implemented in this paper. Here grid, off-grid and on grid combination is assumed, and at the end all three combination are analyzed in this paper.

2.2 Solar PV GDI motor for water pumping

In Fig 2 the Introduction of a new topology for a grid-interfaced solar water pumping system showcases innovation in system design. Addressing the operation of the pump at rated discharge while utilizing grid support addresses real-world scenarios and practical challenges describing the two-stage conversion (DC-DC converter that includes Inverter) demonstrates a comprehensive understanding of power electronics. Emphasizing the improvement in power quality at the AC mains aligns with the current industry needs. Acknowledging the system's suitability for areas with available grid support shows consideration for varied environmental contexts.

Solar PV with Grid Driven Induction (GDI) motor for Water Pumping through MATLAB.

A Microgrid simulated using HOMER Pro, with order number 4686 and ID number 205886, aims to assess operational efficiency, cost-effectiveness, and reliability. Maintenance holds critical importance for both islanded and grid-connected modes to ensure adherence to operational limits and cost minimization at an optimal operating state. Consequently, optimizing hybrid systems becomes integral. The primary stage in constructing any Microgrid involves determining the load requirements at the chosen location profoundly shaping system design.

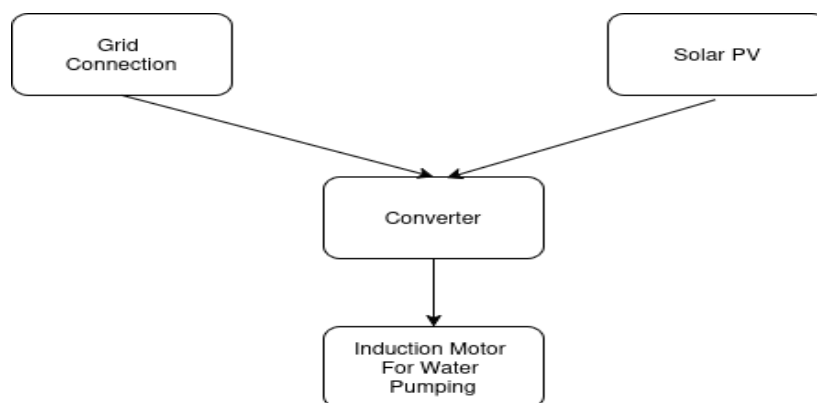


Figure 2: Basic representation for solar-grid pump



Figure 3: Location example for rural village

Any miscalculation here could lead to inaccuracies in demand estimation, potentially resulting in unmet loads or an overflow of energy exceeding the storage system's capacity. Among different available software tools for optimizing mix-systems, HOMER Pro is renowned. Specifically designed for single-objective and nonlinear system analyses, HOMER Pro facilitates decision-making by simulating diverse approaches and technological cost variations. This software adeptly designs the optimal setup for the intended location while respecting user-defined limits. HOMER Pro was utilized to select the most suitable size for the system's renewable energy sources. It explored renewable energy options within a specific region in Likor village, located in the Indian State of Arunachal Pradesh.

The solar resource data Fig 4, specifically the monthly average Solar Global Horizontal Irradiance (GHI), was sourced from the open-access National Renewable Energy Laboratory Database-National Solar Radiation Database. This information pertains to the coordinates of Likor village, Arunachal Pradesh (Latitude: 28.4750005814897, Longitude: 94.78500081025156). The scaled annual average stands at 3.81 kWh/m²/day. The GHI data was acquired and processed through Homer Pro, and further details regarding the analysis steps or specific parameters utilized within the software to generate this data were incorporated in the assessment.

The temperature data as depicted in Fig 5, presenting monthly average temperature in scaled annual average (°C), measures 11.47. This data was procured from



Figure 4: Monthly average solar global horizontal irradiance (GHI)



Figure 5: Monthly average temperature

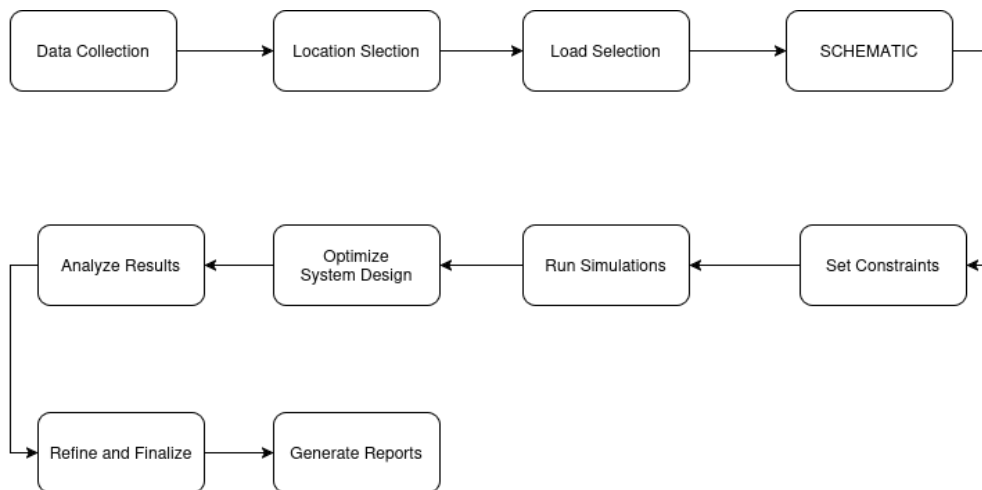


Figure 6: Workflow for modelling

NASA-Worldwide Energy Resource database for Power for the location Likor village, Arunachal Pradesh (Latitude: 28.4750005814897, Longitude: 94.78500081025156). These specifics were utilized within Homer Pro software to simulate the outcomes.

2.3 About HOMER Pro Software

The HOMER software, pioneered by P. Lilienthal at the National Renewable Energy Laboratory in the USA, is specifically crafted for crafting integrated energy systems reliant on renewable sources. This software offers a comprehensive approach to simulate and optimize

these systems while factoring in specific constraints. HOMER, in Fig 5.10 including versions like HOMER Pro and HOMER Grid, operates through three primary steps: simulation, optimization, and sensitivity analysis as seen in Fig 7.

2.4 Comparison obtained through simulation

1. battery/generator /solar (Ba/Gen/S)
2. battery/generator /solar/grid (Ba/Gen/S/G)
3. battery /solar (Ba/S)
4. solar/grid (S/G)

Simulation involves modelling the integrated energy system to evaluate its performance and cost viability across different scenarios. Optimization explores various system combinations to identify the most cost- effective and technologically feasible setup. Sensitivity analysis assesses uncertain factors—like river flow, wind speed, or future fuel costs—impacting the system, providing insights beyond controlled design variables. This three-step process conducted within the HOMER environment encompasses simulation, optimization, and sensitivity analysis for integrated energy system design, aiming to provide optimized, efficient, and sustainable solutions [23].

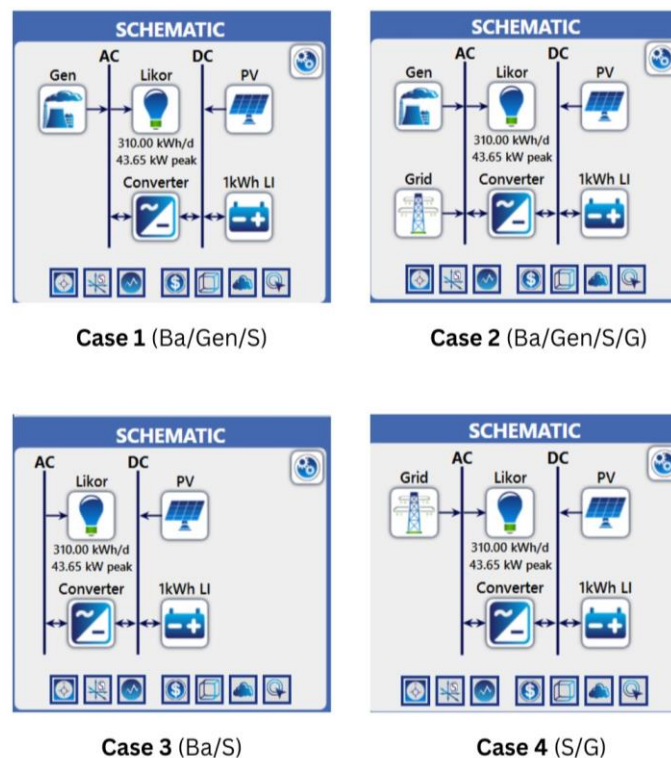


Figure 7: Schematic diagram of the model used in home-pro

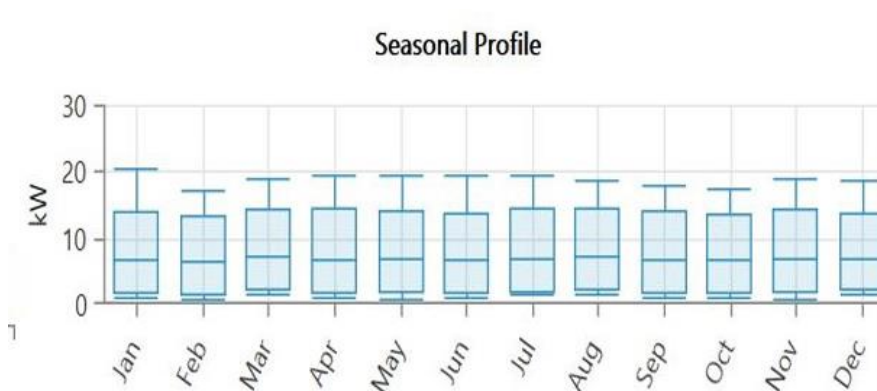


Figure 8: Seasonal energy generation profile for the year 2024

Application of Solar water pump

The power generated from renewable energy is fed to the source of the induction motor to apply it in real world. The work is done in Simulation and field visits along with data collection is done in this case study. Here as a load total dynamic Lead (TDH) is selected as parameter. For 61 household requirement of the village the waler pump capacity depends. After observation for one year it has been seen that during sunny days of summer say July, maximum Water pumping is required approx. 16 l/min. Due to of the geographical constraints of the location the pump performance also decreases. The yearly generation data is shown in fig. no. 8 where during June-July the generation is more. So the required amount of energy also can be provided at the same time. For controlling of the motor driver circuit IoT can be used, which will monitor the parameters as well as accuracy of the system.

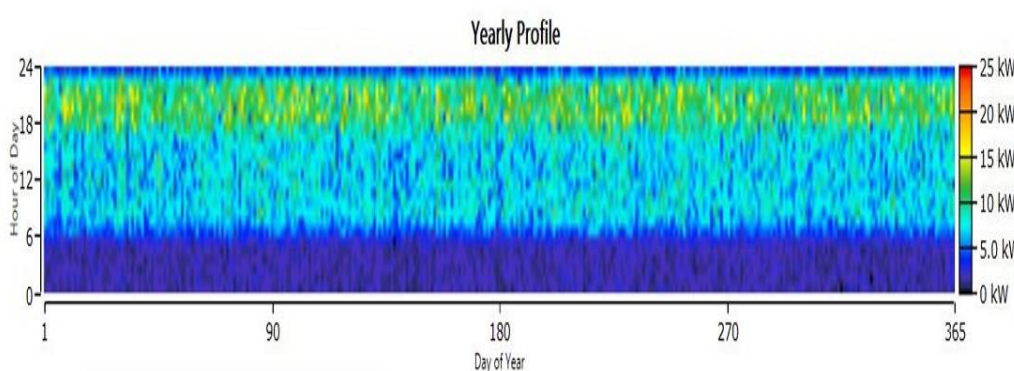


Figure 9: Yearly production for the year 2024

3. Discussion

n this paper pertaining to renewable energy in power systems, a coherent conclusion emerges from a comprehensive review of diverse studies: the transition towards solar energy stands out as a pivotal solution to the escalating energy demands and environmental challenges facing modern society. Solar Photovoltaic (PV) systems, integrated with advanced controls and innovative technologies such as IoT, exhibit substantial potential across various techno-economic applications. These include critical sectors such as water pumping, rural electrification, industrial cooling monitoring, and smart cultivation systems. The collective

findings underscore the robust economic viability, environmental advantages, and notable technical advancements inherent in solar-powered systems. This underscores the pressing need for sustained research efforts, governmental support, and ongoing technological innovations to unlock the full potential of solar energy in addressing our energy needs in a sustainable and efficient manner. To exemplify, a simulation research was conducted to check the techno-economic feasibility of such systems employing tools like HOMER PRO and MATLAB. This investigation focused on the site RVGW+M3 LIKOR, assuming a Discount Rate (%) of 10, an Inflation rate (%) of 5.20, an annual capacity Storage (%) of 5, and a project lifetime (years) of 25. The analysis yielded a Total Net Present Cost of Rs14,08414 and a Levelized Cost of Energy (Rs/KWh) of Rs 2.65. This projection was based on serving 61 households with a household consumption of 1.69 KWh, exemplifying the potential of solar energy integration in optimizing power systems.

4. Conclusion

As from the above discussion exploring future research areas in IoT-integrated solar powered water pumping systems reveals promising avenues for advancement. Techniques focusing on dynamic parameter adjustments based on environmental conditions and fortified security measures are pivotal for the techno-economic feasibility of these systems. Integrating energy storage solutions like batteries ensures reliability during low solar irradiance, contributing to cost-efficiency. Proactive remote monitoring and maintenance powered by IoT sensors promise cost-effective system upkeep. Integrating these systems into smart grids amplifies economic benefits by stabilizing grids and enabling demand response. Advanced data analytics offer insights for informed decisions, optimizing resource allocation. Community engagement studies uncover socio-economic factors for sustainable implementation. These research avenues strive to elevate economic viability, efficiency, and practicality, addressing technical hurdles while enhancing cost-effectiveness in remote regions.

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