# A comparison of the performance of stand-alone, grid-connected, and hybrid renewable energy systems for rural applications.

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***ABSTRACT:*** ***Due to technical advancements, fast development in sectors, and a rise in household energy consumption, global energy demand has grown by a factor of ten. This prompted engineers and planners to consider and develop methods for harvesting non-fossil fuel energy sources. Solar, wind, biomass, and micro hydro are some of the resources utilized to produce energy throughout the globe, depending on the resources available. This study compares the performance of several stand-alone solar photovoltaic (PV), grid-connected PV, and hybrid renewable energy system (HRES) systems across the world. A solitary PV system is used to provide energy to a single home or a small habitat/hamlet. Hybrid energy systems combine two or more energy sources to provide electricity for rural electrification in off-grid areas and grid-connected PV systems, with surplus electricity pumped into the grid producing extra revenue. This article discusses the efforts of different academics from across the world on renewable energy sources, especially for rural electrification. Aside from that, the use of renewable energy for Plug-in Electric Vehicles (PEV) was researched all over the world.***

***KEYWORDS:*** ***Eco-Friendly, Green House Gases, Plug-In-Electric Vehicle, Renewable Energy, Solar Energy***

## 1. INTRODUCTION

Fossil fuel is the primary source of power, and it emits a large amount of hazardous gases into the atmosphere. Reduced greenhouse gas emissions from our environment are a major worldwide issue these days, and this may be accomplished by using renewable energy to provide cleaner electricity. Renewable energy sources such as solar PV, wind, biomass, biogas, small hydro, concentrated solar power, and others are increasingly widely utilized to produce electricity across the globe to decrease reliance on fossil fuels and pollution[1]. The United Nations has launched an effort to encourage countries to generate clean and green energy. As a consequence, many nations have taken various strategic steps to decrease their greenhouse gas emissions. The use of non-conventional energy sources is rapidly growing across the globe in order to address the severe energy crisis and mitigate the consequences of global warming. Renewables are now the world's fastest-growing energy source, with consumption expected to rise by 2.6 percent each year between 2012 and 2040 [2]. Renewables produced 23.70 percent (1849 GW) of worldwide power production in 2015, out of total generated energy of 6399 GW. The energy consumption of various energy sources, which shows that by 2040, renewable energy, coal, and liquid fuel consumption will all be much higher. Up to the end of 2015, the world's total renewable power producing capacity was 785 GW without hydropower and 1849 GW with hydropower. China, the United States, Germany, Japan, India, Italy, and Spain are the world's top seven renewable energy producers. These top seven nations' capabilities, including hydropower, are given in. Different governments, including India's, are now giving financial support to promote the development and use of renewable energy to satisfy rural populations' basic energy requirements [3]. In the field of renewable energy, extensive research has been done globally, including feasibility studies, computer modeling, control, and experimental work. For energy production, significant research was conducted on optimal size, modeling, and feasibility studies of stand-alone solar PV systems, either ground mounted or rooftop systems[4]. Techniques for hybrid energy system optimization and concluded that each size strategy has its own characteristics and possibilities for sizing hybrid energy systems, and the decision should be made based on the kind of application and the needs of the user. In Canada, we built and optimized a renewable energy-based micro grid, and we discovered that increasing the price of diesel resulted in a substantial decrease in CO2. They also found that a diesel-renewable mixed micro grid has the lowest NPC and has a lower carbon footprint than a stand-alone diesel micro grid, and that a completely renewable micro grid with zero carbon footprint is the most desired, despite having a higher NPC [5]. The performance data of 260 PV systems placed in various locations across the world was examined, and it was discovered that yearly performance ratio (PR) values vary depending on the kind of installed system. They assessed the PR of 170 grid-connected PV systems and discovered that PR varied considerably across plants, ranging from 0.25 to 0.90 on average [6]. Off-grid home systems have a PR ranging from 0.2 to 0.6, depending

on the availability of a backup system, while professional off-grid systems have a PR ranging from 0.05 to 0.25. In Malaysia, the building integrated PV/diesel hybrid system was optimized, and it was recommended that the PV-diesel system is more practical than a stand-alone PV or diesel system since it lowers the system cost by 35%. The results of several research on standalone PV, grid-connected PV, and hybrid systems for rural electrification performed across the globe are presented. By the end of the year, solar PV installations had reached a new high of 50 GW, bringing the total worldwide capacity to 227 GW. Many solar projects were established by various nations to electrify their distant and inaccessible regions, as well as offer incentives for the installation of numerous solar PV systems on the roofs of public and commercial organizations, as well as residential structures [7]. Many scholars looked at the performance of these installations and came up with some interesting results that would be very useful in future study.

## 2. LITERATURE REVIEW

PV power reached grid parity in certain particular areas and proved to be an economically beneficial source of electricity, according to a study of the liveliest cost of energy (LCOE) of solar PV systems [8]. Independent studies on standalone solar and biomass systems. Because of its great efficiency and cheap cost of energy, this research recommends a biomass energy system for rural regions (LCOE). Their HOMER cost optimization study indicates that a stand-alone biomass system is more cost-effective than a stand-alone PV system. the optimal modeling and sizing of a standalone PV/Battery system in Klang Valley, Malaysia, using numerical algorithm, and found that the optimal sizing ratio of PV array is 1.184, battery is 0.613, and levelised cost of energy studied the performance of a standalone PV system for an isolated island in Hong Kong, and found that output of PV system decreased significantly with increase in Celsius. The actual array production was 3.08 kW h/kWp/day, compared to the expected 4.94 kW h/kWp/day. Over the past 12 years, standalone solar PV and hybrid energy systems have been utilized to electrify off-grid locations in various regions of the world. Solar energy, according to the research, is a cost-effective and environmentally beneficial power option for any load scenario in rural regions that are off the grid [9]. They proposed that any other source of energy may be added to solar PV to increase its reliability and cost effectiveness. rooftop solar PV systems placed in a cluster of communities in Australia, according to research. They discovered that for a home with a 100 m2 floor space, a minimum solar system capacity of 1 kWp is required. They discovered that inverter failures induced by circuit breaker failure led certain systems to be down for 16–266 days. A case study of a typical 2.32 kWp standalone photovoltaic system in New Delhi (India) in four different weather conditions: clear, hazy, partly cloudy foggy, and completely cloudy/foggy. With a total energy production of 1293 kW h/year, the inverter efficiency was determined to be 95.6 percent, while the system efficiency was 4.8 percent. A simulation model for PV system size in several European cities showed that solar radiation variation has a significant impact on the dependability and cost of PV system sizing. In Nepal, the potential of using SPV for remote region electricity was investigated. They came to the conclusion that SPV is not cost viable in urban regions, but it is an alternative source of energy in rural Nepal, despite its higher cost. They also recommended that rural electrification projects not be chosen only on the basis of financial gain, but also on the basis of social benefits. In 531 rural homes in three provinces in western China, impact research on small-scale stand-alone renewable energy technologies for rural electrification was conducted, with the conclusion that off-grid renewable energy is both cost-effective and dependable. Similarly, numerous researchers from all around the world have studied the performance of different PV systems. The results of a few of these investigations are given. Grid-interactive PV systems aid in the efficient use of produced energy. Many grid-connected PV systems have been built throughout the world, and academics are studying them. Using HOMER, research was conducted in Nigeria to determine the feasibility, dependability, and economic performance of an 80-kW solar PV-grid linked system. It was discovered that the grid connected solar PV system may be economically feasible. He believes that a solar PV system provides a dependable source of energy that reduces reliance on diesel generators, lowering greenhouse gas emissions. Power production from hybrid energy systems was examined for usage in rural and semi-urban regions in Nigeria's northern region, and it was discovered that the PV/DG/Battery hybrid system is the most cost-effective choice for electricity generating. The levelised cost of energy for this hybrid energy system ranges from $0.348/kW h to $0.378/kW h depending on the rate of interest, according to the best simulation findings. These expenses are lower than the costs of running a diesel generator alone (without a battery), which range from $0.417 to $0.423 per kW hour. For both grid-connected and freestanding systems, different literature surveys on technical alternatives, modeling, feasibility, economic, and environmental studies were conducted. In Punjab, researchers performed a performance study on a 190 kWp grid interactive solar PV power plant, finding that the final yield, reference yield, and performance ratio range from 1.45 to 2.84 kW h/kWp-day, 2.29–

3.53 kWh/kWp-day, and 55–83 percent, respectively. The plant's average annual energy output is 812.76 kW h/kWp, with an 8.3% system efficiency. The monthly average daily PV, system, and inverter efficiencies for a 13 kWp roof mounted grid connected PV system varied from 5% to 10%, 3–7%, and 50–87 percent, respectively, while the performance ratio ranged from 0.29 to 0.66. This system's payback time was determined to be 7.5 years, and it is environmentally benign and beneficial to the environment since it reduces annual emissions. A comparison study in Thailand of three different types of grid-connected photovoltaic power plants, namely solar residential roof top, integrated ground mounted roof top (330 kW), and utility scale (38.5 MW), and discovered that the utility scale solar system had the lowest cost of electricity at $0.27/kW h. Residential solar roof top and ground mounted roof top systems have energy costs of $ 0.46/kW h and $0.29/kW h, respectively. They came to the conclusion that the government's new feed-in tariff schemes for residential, integrated ground-mounted, and utility-scale systems with installed capacity more than 1 MW may be viable for investors. The grid-connected hybrid power system was researched and analyzed, and it was discovered that the grid-connected hybrid PV/wind power system is the most appropriate and cost-competitive for that area. performed a study of grid-connected PV system issues and discovered that inverter failure is the most common problem with grid-connected systems [10]. They also highly recommended that inverters with a unity power factor rather than a variable power factor should be used since a variable power factor may create a lot of balanced conditions with high PV penetration, increasing the risk of islanding. More grid-connected PV system research is provided. Hybridization of energy sources improves system dependability since any component's shortcomings are compensated by others, although appropriate component selection and size are critical in the design of such systems. Globally, much study on the use of renewable energy sources for rural electrification has been carried out. Several HES configurations have been extensively documented in the literatures, including PV-wind, PV-DG, wind-DG, and small hydro-DG. These articles provided detailed descriptions of hybrid energy systems' performance, practicality, and economic features in off-grid rural electrification. In Bangladesh's rural regions, research was conducted on a hybrid system that combined biogas and solar resources to satisfy household energy requirements. They discovered that a hybrid biogas-solar PV system can satisfy the cooking and power needs of families with 3–6 livestock. Households may save a significant amount of money by replacing traditional fuels with hybrid systems, which is more than the entire annualized cost of installation of the hybrid systems. With a cow dung price of $ 0.10/m3, the COE (electricity) was determined to be $ 0.263/kW h, increasing to $ 0.36/kW h if the cow dung price was raised to $ 0.3/m3. PV-biogas energy systems outperform grid and diesel systems across a broad range of fuel prices, according to a case study conducted in a rural hamlet in Hyderabad, India. According to the economic study, a biogas plant with an initial expenditure of about 20,000INR ($303) per family may efficiently satisfy every household's energy requirement and be paid back within an acceptable payback time. Because the grid no longer supplies electricity for even half of the time, the rate of return for the local community operating the biomass plant is also viable. In West Bengal, India, research on rural electrification using integrated renewable energy systems (IRES) including various sources such as solar and biogas found that IRES had reduced capital and electricity costs, with COE $0.289/kWh. They also believe that rural electrification initiatives in poor nations enhance the quality of life in distant communities, and that the MHP-biomass-biogas-energy-plantation-wind-SPV combination is the most dependable and cost-effective, with a COE of 3.36 INR/kWh. Using an Integrated Renewable Energy System, we optimized the off-grid rural electrification techniques of seven un-electrified villages in the Almora area of Uttarakhand, India (IRES). During the modeling and optimization of IRES, four alternative combinations of renewable resources were examined to guarantee dependability criteria such as the energy index ratio (EIR) and anticipated energy not provided (EENS). By including the customer interruption cost, the best system dependability, total system cost, and cost of energy (COE) have been determined (CIC). Among all the scenarios considered, scenario 4 (MHP-Biomass-Biogas-Energy Plantation-Wind-SPV) was found to be the most reliable and cost effective, and has been proposed for the study area. In Argentina's Jujuy region, research was conducted on 12 isolated off-grid hybrid renewable energy systems that were built for rural electrification. Seven of them are hybrid systems that include both solar and DG, while five are just solar PV systems. They discovered that the load demand has a distinct impact on the system.

## 3. DISCUSSION ON GRID CONNECTION USED FOR RURAL ARES

The load of a PV-only system is self-regulating, whereas the load of a hybrid system increases significantly, consuming more fuel. A study of the issues surrounding rural electrification in Asia and the Pacific using renewable energy sources. They conducted two case studies in Bangladesh and Fiji, finding that 100 percent of respondents are satisfied with the system, which has improved their lifestyle and increased their working and study hours by 87 percent, while 40 percent of respondents get their income from the system directly or indirectly. A cost optimization of a hybrid energy system consisting of SHP-biogas-biomass-SPV-DG for

supplying electricity to a cluster of nine remote un electrified villages in Uttarakhand, India Chaurey and his colleagues reviewed decentralized rural electrification and concluded that the PV system is the most often used technology for fulfilling basic electrical requirements in rural regions. Another study on hybrid renewable energy systems (HRES) for power production found that HRES has enormous potential to fulfill the energy needs of distant, isolated, and off-grid locations across the world. They believe that broad adoption of hybrid renewable energy systems not only solves energy problems, but also guarantees a green and sustainable environment. In Florida, USA, a techno-economic research of a solar-biomass hybrid system was conducted, with the conclusion that hybrid systems with solar-biomass components are practical and had lower energy costs than other systems in the area. In a study of Ireland's hybrid energy system, researchers discovered that wind energy has the highest potential for energy production and accounts for 10% of the country's energy consumption. It was also discovered that a grid-connected hybrid system using wind energy as a component emits no $CO_2$. conducted a research on electricity production from PV-diesel hybrid systems in off-grid regions in France without storage systems and recommended that the size of the DG should be equivalent to the peak demand for PV-diesel system dependability. In Turkey, researchers compared stand-alone and grid-connected hybrid systems and discovered that the grid-connected hybrid system had a greater acceptance rate than the stand-alone system. In Saudi Arabia, researchers evaluated a PV-diesel-battery system for rural electrification and found that a diesel price of $0.1/l resulted in an LCOE of $0.170/kW h. The research also discovered that as PV capacity grows, DG operating hours' decrease. The economics of solar-wind-diesel hybrid systems for remote area electrification in Saudi Arabia, and found that with 24 percent RE penetration (solar 14 percent + wind 10 percent), hybrid energy systems for electricity generation resulted in a 16 percent $CO_2$ reduction, and concluded that hybrid renewable energy systems are an expensive and ineffective source of power when compared to fossil fuels. They also came to the conclusion that PV and wind turbines should be combined with an optimum controller architecture for reliable power delivery. They also discovered that SDP management may result in substantial cost savings for consumers and grid load shifting to reduce a customer's energy costs under a time-of-use tariff. For a rapid charging electric urban bus with hybrid energy storage system, Yu et al. present a model in the loop and optimized fuzzy logic based energy management approach. In comparison to the conventional fuzzy logic based energy management strategy, the optimization method resulted in a reduction of 15.8 percent output energy from the battery, a reduction of 3.8 percent impact on the battery, a reduction of 1.3 percent total cost of energy, and a 3.8 percent improvement in comprehensive performance. An energy management approach for PHEVs that incorporates real-time traffic flow velocity data. DP (Dynamic Programming) calculates the best SOC (State-of-Charge) trajectory in real time, at a pace that matches the rate of traffic data updates (300 s). In a highway driving scenario, simulation findings indicate that the predictive energy management approach using dynamic traffic data may reach 94–96 percent fuel optimality of the deterministic DP benchmark. The importance of renewable energy and powertrain optimization in reducing daily carbon emissions from plug-in hybrid electric cars. The ICE (internal combustion engine), HEV (hybrid electric vehicle), and three PHEV (plug in hybrid electric vehicle) heuristic scenarios are presented, and their drawbacks are shown via comparisons with instances of wind power penetration and fast system optimization. A comprehensive optimization methodology for PHEV battery dimensioning, charging, and on-road power management, with the goal of reducing total $CO_2$ emissions daily. For a small-size PHEV, three scenarios with high, medium, and low grid $CO_2$ levels are investigated. The findings show that when grid $CO_2$ drops, the PHEV becomes more reliant on electricity, and its recharging happens around the lowest carbon period. A thorough review of the current advances in optimization-based algorithms was conducted, and it was discovered that EMS cannot be really optimized until precise information about the future path is provided. A linear program with a defined goal was used to optimize a collection of electric cars at charging stations. They discovered that the energy consumption of electric vehicles (EVs) in normal circumstances is smaller than the energy consumption in disturbed situations after evaluating the data. A feasibility assessment of a solar-wind-battery hybrid system on a remote island off the coast of Hong Kong concluded that current DG could be replaced entirely by renewable energy sources. In India, a research was conducted on decentralized renewable energy sources for rural electrification. Biomass gasification-based systems are more cost competitive than solar systems or even grid expansion for towns distant from the current grid line, according to the study. Although grid power has a low production cost, the effective cost per unit electricity for grid expansion is greater than for local renewable energy-based systems. Owing to the considerable distance between the village load center and the current grid, this is due to high grid expansion costs and related transmission and distribution losses. Research on the use of renewable energy in rural electrification in Malaysia found that renewable energy sources, especially solar and hydro, are the greatest options for electricity generation in energy-poor areas. The renewable energy sources for rural applications in Japan show that, since grid power in Japan is costly, renewable energy produced from solar-wind-hydro systems is cost-effective when compared to grid electricity, with a 50% $CO_2$ reduction. In

Brazil, research on decentralized energy supply using renewable sources such as solar PV and a biogas digester fed by goat dung found that this hybrid system may be utilized as a sustainable energy source in rural areas. A cost-benefit analysis of hybrid energy systems for rural electricity in Nigeria shows that the PV-diesel-battery system is the most efficient, emitting the least COE and $CO_2$. The practicality of providing power to a community in Ethiopia that is distant from the grid using a solar wind-DG hybrid system is viable for each of the three communities.

## 4. CONCLUSION

An effort has been made to collect the results of many researchers' study on hybrid system performance analysis in various places across the world. The purpose of this article is to assist interested researchers in the design, size optimization, and performance analysis of hybrid renewable energy systems with an emphasis on rural applications. Aside from that, the research work done in the area of PHEV was also addressed in this article. Sizing optimization and economic analysis of hybrid energy systems with an emphasis on rural electrification. The major uniqueness of this study is that it includes research on PHEV paper. Academicians and scholars will benefit from this article. key decision-makers in the renewable energy sector. The most important the study's findings include the following: A renewable energy system based on pumped hydro storage is suitable. In distant locations, there is an option for complete energy autonomy. If the load is less than 75 kWh/day, a PV-wind system is cost-effective and the load point is 50 kilometers or more from the grid Rural electrification with renewable energy sources may save up to 50% on electricity costs. Emissions from residential areas account for 99 percent of total $CO_2$ emissions. Compared to grid and diesel methods for electricity. It is preferable to take use of hydro potential in areas where it exists. It is a resource that may be used as the primary component of HRES. Renewable-based energy may not always be a cost-effective option. Unless appropriate assistance is available, and effective alternative for remote applications by the federal government

**References:**


[1] C. Nagamani, G. Saravana Ilango, M. J. B. Reddy, M. A. A. Rani, and Z. V. Lakaparampil, "Renewable power generation Indian scenario: A review," *Electr. Power Components Syst.*, 2015, doi: 10.1080/15325008.2015.1013164.

[2] a. K. A. K. Vasudevan *et al.*, "Advanced Coatings for Structural Materials: Science and Technology," *Surf. Coatings Technol.*, 2013.

[3] G. Y. Obeng and H. Evers, "Solar PV rural electrification and energy-poverty: A review and conceptual framework with reference to Ghana," *ZEF Working Paper Series*, 2009.

[4] R. Sharma and S. Goel, "Solar photovoltaic system design and its reliability," 2016, doi: 10.1109/PCITC.2015.7438151.

[5] D. EL Pebrian and A. Yahya, "New mechanised system for rcle spraying of palms seedling emergence," *Sci. Agric.*, 2011.

[6] I. A. Ibrahim, A. Mohamed, and T. Khatib, "Optimal modeling and sizing of a practical standalone PV/battery generation system using numerical algorithm," 2015, doi: 10.1109/SCORED.2015.7449372.

[7] K. S. S. Pundir, N. Varshney, and G. K. Singh, "Comparative study of performance of grid connected solar photovoltaic power system in campus.," *Proc. Int. Conf. Innov. trends Sci. Eng. Manag. New Delhi*, 2016.

[8] A. Jain, E. Srinivas, S. Raman, R. R. Gaddam, V. V. S. S. Haritha, and N. Venkata Srinath, "Sustainable energy plan for an Indian village," 2010, doi: 10.1109/POWERCON.2010.5666618.

[9] J. Smith *et al.*, "The potential of small-scale biogas digesters to alleviate poverty and improve Long term sustainability of ecosystem services in Sub-Saharan Africa," *1st World Sustain. Forum*, 2013.

[10] K. Kusakana, J. L. Munda, and A. A. Jimoh, "Feasibility study of a hybrid PV-micro hydro system for rural electrification," 2009, doi: 10.1109/AFRCON.2009.5308185.