International Journal of Computer Communication and Informatics

DOI: 10.34256/ijcci2316

# Review of Hybrid Wind-Solar PV Technology in the Generation of Electricity


T. Jayakumar [a,*], P. Ponmurugan [b], B. Karthik [c], K.C. Anandhan [d], S. Ragul [e], Neelam Sanjeev Kumar [f], D. Rajkumar [g]

[a] Department of Biomedical Engineering, Nandha Engineering College, Erode, Tamil Nadu, India.

[b] Department of Research, Meenakshi Academy of Higher Education and Research, Chennai-600078, Tamil Nadu, India.

[c] Department of Mechanical Engineering, Asian College of Engineering and Technology, Tamil Nadu, India.

[d] Department of Electrical and Electronics Engineering, Shree Venkateshwara Hi-Tech Engineering College, Gobi, Tamil Nadu, India.

[e] Department of Electrical and Electronics Engineering, Kongunadu College of Engineering and Technology, Thottiyam, Tamil Nadu, India.

[f] Department of Biomedical Engineering, Saveetha School of Engineering, Chennai, Tamil Nadu, India.

[g] Department of Electrical and Electronics Engineering, Velalar College of Engineering and Technology, Erode, Tamil Nadu, India.

* Corresponding Author: jayakumart@gmail.com


Received: 03-04-2023, Revised: 12-05-2023, Accepted: 22-05-2023, Published: 30-05-2023

**Abstract:** Achieving sustainability by utilizing alternative energy sources viable technological possibilities for creating sustainable energy, the sun, biomass, wind, geothermal resources, hydropower, and ocean resources are considered. Despite the fact that the total amount of energy produced by PV cells and wind turbines is still far less than that of fossil fuels, their ability to generate electricity has significantly expanded in recent years. This article provides an overview of the Solar-Wind hybrid power system, which generates electricity by combining the Sun and Wind, two renewable energy sources. Microcontrollers are widely used in the field of system management. We can maximize the utilization of those resources by employing this strategy, which takes into account the distinct production processes of each resource. Furthermore, it increases dependability and decreases reliance on any single input. This hybrid solar-wind power generation system is suitable for both industrial and residential applications.

**Keywords:** Solar, Wind, Power Generation

## 1. Introduction

Supplying sustainable energy has emerged as the major concern of the 21st century on economic, political, and sociological levels. The global energy industry has already had a significant negative impact on the environment as a result of greenhouse gas (GHG) emissions that are either directly or indirectly discharged into the atmosphere. Greenhouse gas (GHG) emissions cause pollution, global warming, and other issues that limit our ability to conserve natural resources. The use of fossil fuels for energy-related purposes accounts for approximately 70% of global $CO_2$ emissions, making it one of the leading culprits. Electricity, which is critical to any society's growth, is already responsible for 37.5% of global $CO_2$ emissions, or 7700 million tons per year. This demonstrates that a significant shift is required to decarbonize electricity globally [1, 2].

One of the most popular energy sources used by people worldwide is electricity. According to literature searches, more than 1.64 billion people worldwide, with a large proportion living in rural Africa and Asia, are completely powerless. Given the large number of people who live without electricity, it is clear that access to electricity is more of a privilege than a basic human right in some countries. Surprisingly, the majority of the world's powerless people live in low-income households in rural areas where renewable energy sources are easily accessible and less expensive to research than expanding infrastructure. The effects of global warming and climatic change have been obvious for centuries. Extreme weather events (severe flooding, tsunamis, and hurricanes), changes in precipitation and seasonal patterns, sea-level rise, and an increase in the world's average temperature are just a few examples of the most compelling evidence. The decrease in heat demand and the increase in cooling demand, both of which affect global average temperatures, are both energy- and carbon-intensive processes. According to a recent study, global warming and climate change kill approximately 16,000 people each year, and if fossil fuels continue to be the world's main source of energy, this number is predicted to double by 2020 [3, 5]. In order to address this complex challenge, numerous investigations were conducted to seek an appropriate treatment for the rising carbon emissions linked to the global transportation and electricity sectors. The application of combined heat and power systems, which generate both electricity and heat from efficient fossil fuels as described in the study, the use of technologies of renewable energy for micro-scale, medium-scale, small-scale, and large-scale energy applications; and the use of existing fossil fuel power production technologies with Carbon Capture System (CCS). Renewable energy sources have significant constraints when it comes to producing power, despite being the most environmentally responsible option for reducing emissions from energy use. The most difficult challenge with renewable energy sources is the intermittency impact, because, unlike conventional energy sources, RESs are dependent on meteorological conditions and the seasons of the year. According to the unanimous opinion of the world's energy experts, considering generation at the diurnal level and completing various renewable energy technologies in the form of a hybrid is the most straightforward strategy that could be used to address the intermittent nature of renewable energy sources in the production of electricity. This study will present a novel approach for investigating the viability of micro-generation using the wind-solar hybrid electricity generation system for power production and application to the tiny electric automobile in a coherent and integrated manner [6, 7].

Despite the intermittency effect, renewable energy sources are widely regarded as the most promising technologies for successfully implementing modern sustainable energy policies. Renewable energy sources have already been identified as having enormous technical potential by the global energy industries. The total amount of power consumed worldwide is expected to reach 20 TW by 2020. On the other hand, the amount of radiation striking the planet's surface is approximately 173,000TW. This demonstrates how, when harnessed, solar energy alone can meet the entire world's electricity demand. Consider the potential of solar resources in the energy industry: 1kW of power can be generated for every $1km^2$ of solar radiation that strikes the earth's surface. Simply put, the sun's energy is being carried directly here. Hydro, Wind, geothermal, tidal, and other solar-dependent energy sources can be combined to generate significant amounts of energy without the use of fossil fuels.

As previously stated, the intermittency of renewable energy systems is their most troublesome feature due to their reliance on climatic conditions. In this regard, single renewable energy systems have been developed and tested in various case studies, though they are still in the early stages able to provide uninterrupted electricity to end users. As a result, additional research is required to optimize their integration with other energy sources. To address this issue, micro-generation using hybrid renewable energy sources can provide more consistent and dependable electricity than a single renewable energy source. Some of the key advantages of micro renewable hybrid systems are: Lowering carbon emissions, as the carbon footprint is the only emission associated with the majority of renewable energy technologies. Greater energy supply security because renewable sources are constantly replenished. As a result, global fuel poverty will decrease. This will increase fuel security. A higher-value generation profile, as well as a reduction in electricity transmission and distribution losses because the generation equipment for micro generation is located close to where the power is required, it will outperform the conventional grid in long-distance electricity transmission due to transmission and distribution losses. This means that the transmission and distribution systems are less stressed. It would result in lower billing for city dwellers in the case of on-grid applications and would be less expensive for the government and individuals than grid extension. The technology allows for the integration of a large number of micro generation units (primarily from renewable sources) without interfering with the utility network's operation. Because it involves the combination of two or more renewable technologies that complement one another in energy generation, it can serve as a solution to the intermittent effect of renewable energy power generation.

Given the benefits mentioned, it is impossible to overestimate the potential of using renewable energy resources to generate micro renewable electricity in rural areas. Furthermore, because of the larger landmass and low electricity consumption, nearly all of the challenges with renewable energy generation, such as wind turbine noise and a lack of space for solar PV panel installations, may be addressed. The ability to shade animals during rainy and hot weather is the most recent benefit of this technology for rural residents. Low-carbon technologies, such as micro power and heat generation, must be integrated into the Indian National Solar Mission and the Indian Government Renewable Energy Missions to support ecologically sustainable growth and address India's energy security issues. However, without expanding the national grid, rural India can be electrified through micro generation in a way that is both economically and environmentally sustainable for the government, which has been a fundamental priority for every administration since the country's independence has recognized its importance to the country's success.

## 2. Solar Energy

Two of the greatest political, economic, and societal challenges of the twenty-first century are sustainable modes of transportation and reliable sources of electricity. The combustion of fossil fuels for electricity and transportation accounts for roughly 60% of total carbon emissions. Electricity production and consumption account for 37.5% of global CO2 emissions, or 7.7 billion metric tons of $CO_2$ per year. This demonstrates the critical need for a global decarburization of electricity. But what happened to the intermittent nature of renewable energy sources like wind and solar, whose output varies seasonally? This is why renewable energy technologies are not regarded as a long-term solution to global energy supply and security concerns. Examining diurnal, or hourly, generation and combining it with other renewable energy technologies to create a hybrid is the most straightforward way to deal with the impact of renewable energy sources' intermittent output in real-time and simulation environments. To address the issue of renewable energy technologies' intermittent nature, researchers from all over the world are evaluating the viability, performance, and practicability of renewable energy systems for electricity production. Wind-solar hybrids, for example, are regarded as one of the most promising renewable electricity generation sources in terms of environmental sustainability. Multiple sources of renewable energy, as demonstrated by a number of case studies, can mitigate the intermittent issues that have plagued renewable electricity generation technologies in the past. In comparison to the use of renewable electricity generation sources alone, hybrid renewable energy systems have been practically demonstrated to generate autonomous, sustainable power and stable, for on-grid and off-grid applications by ensuring a more consistent energy feed into the grid. Furthermore, new hybrid renewable technology shows that significant progress can be made, particularly in rural electrification, where the majority of the population lives off-grid in low-income homes in villages where renewable energy resources are abundant and less expensive to explore than expanding the grid. As demonstrated by the majority of literature reviews, using meteorological datasets to investigate the potential of renewable electricity generation has the potential to provide individuals and the government with clear and concise information for the creation of policies for the penetration of renewable energy resources in electricity generation. Table 1 and 2 shows the Solar PV and wind installed countries comparison [8, 9].

## 3. Wind Energy

The movement of large amounts of air across the Earth's surface is included in the definition of wind, which refers to the global circulation of gases. Coriolis forces, which are caused by the earth's rotation and are a direct result of the uneven suns, heating of the surface of the earth, are responsible for circulation and movement from a higher-pressure region to a lower pressure region. Wind energy harvesting is a centuries-old technique used in the Middle East for at least 1400-1800 years. Wind energy was first used to power sailboats and agricultural irrigation. Wind power was likely first used for water pumping by the Chinese around 200 B.C., according to historical and archaeological evidence. The belief that conventional energy sources would eventually peak and decline led to the expansion of wind energy generation in the mid-twentieth century, which dates back to around 1877. Wind variability is a major factor in all scales of wind-powered electricity generation. Because wind energy is directly influenced by weather and climate, it exhibits high levels of natural variability. Because wind resources vary, it is difficult to predict whether there will be enough supply to meet demand. The amount of electricity that can be generated by wind turbines at a specific location is directly proportional to the availability of wind energy; thus, understanding wind variability at a site of interest is critical. Wind energy availability is highly unpredictable in terms of both location and time. The broad categories used to describe wind energy variability are geographic and temporal variations [10, 11].

**Table 1.** Solar PV Installed Countries

| Country | 2017 Total Capacity (MW) | 2018-2022 Compound Annual Growth Rate (%) | 2017-2022 NewCapacity(MW) |
|---|---|---|---|
| India | 19,047 | 39% | 78,384 |
| USA | 51,527 | 17% | 62,643 |
| China | 130,751 | 21% | 209,000 |
| Germany | 42,973 | 8% | 20,264 |
| Japan | 49,251 | 10% | 29,300 |
| Italy | 19,392 | 7% | 7,533 |
| Australia | 7,308 | 26% | 15,662 |
| France | 7,999 | 20% | 11,703 |
| Mexico | 1,174 | 67% | 14,078 |
| UK | 12,676 | 3% | 2,065 |

Because different geographical locations experience different wind conditions at different times, understanding the relationship between geographical wind variation and the total potential of wind resources for wind energy production is critical. The geographic variation in wind speed is classified using three scales: small, medium, and large. In large-scale climatic regions, latitude plays a significant role in determining wind variability. Furthermore, the land, sea, forest, mountains, and plains of the location all influence the microclimate and, as a result, the wind patterns. It should be noted in the section titled "Local Geographic Variations" that the topography (hills, trees, buildings, etc.) of the area in question determines the local wind. The roughness height is critical when describing wind properties based on geographical variation [12, 13].

Table 2. Wind Installed Countries

| Country | 2017 Total Capacity (MW) | 2018-2022 Compound Annual Growth Rate (%) | 2017-2022 New Capacity (MW) |
|---|---|---|---|
| **Japan** | 32,938 | 6.7% | 35,129 |
| **India** | 56,189 | 5.6% | 3,122 |
| **USA** | 89,077 | 8.5% | 7,588 |
| **China** | 188,392 | 12.2% | 23,000 |
| **Germany** | 23,097 | 1.7% | 23,494 |
| **Australia** | 13,753 | 11.3% | 15,309 |
| **UK** | 9,506 | 4.8% | 9,958 |
| **Mexico** | 12,240 | 4.6% | 12,816 |
| **France** | 12,769 | 15.2% | 14,707 |
| **Italy** | 19,069 | 10.0% | 20,970 |

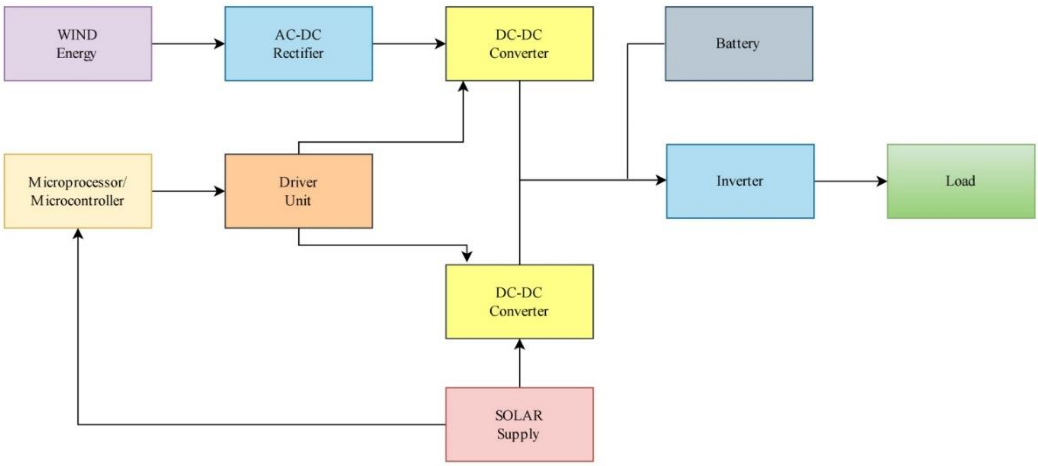


Figure 1. Block Diagram of Hybrid Wind and Solar Energy Generation

## 4. Hybrid Wind and Solar Energy Generation

Wind's temporal variability reflects the consideration of timescales. Only short-term forecasts of wind behavior are possible due to recurring patterns in the atmosphere. Long-term, short-term, and even micro scale temporal variability characterizes wind energy. Despite the fact that turbulence is relatively clear and predictable on an annual time scale compared to larger time scales, the variations of wind energy under large scale temporal variability, such as decades, annual, etc., are poorly understood. This event is thought to be caused by atmospheric wind circulation. The atmospheric pressure belts that control circulation shift north in July and south in January as the sun moves between the Tropics of Cancer and Capricorn. Figure 1 shows the block diagram of hybrid wind and solar energy generation.

Even as our understanding of wind speed improves on shorter time scales, forecasting it remains difficult. Wind variability on this scale is determined by the response to temperature differences between nearby oceans and large land masses. Figure 2 shows the hybrid wind and solar energy system. Understanding wind variability on micro time scales of seconds or less is significantly more advanced than on longer time scales, because the response to daily (diurnal) variations in solar heating is controlled at this time scale. Table 3 compares the various literatures related to hybrid wind-solar power generation.

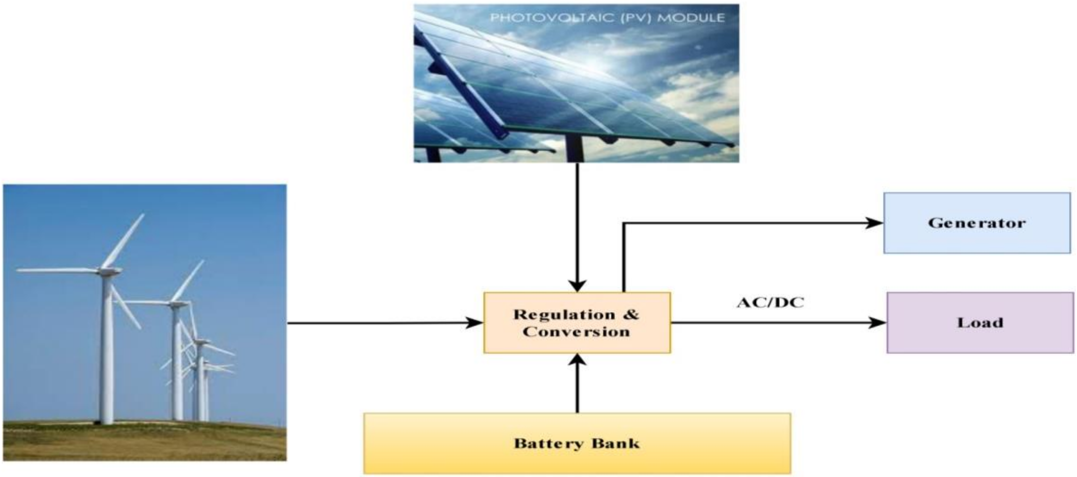


Figure 2. Hybrid Wind and Solar Energy System

Table 3. Comparison of Literature

| Refs. | Technology | Method | Findings |
|---|---|---|---|
| Pantos, 2011. [14] | WECs | Stochastic optimization | The study employs three case studies to assess the efficacy of the proposed formulation while |

| | | | |
|---|---|---|---|
| | | algorithm using GAMS/ SCENRED | accounting for various optimization criteria. Higher transportation costs for EDV users are a trade-off for a cleaner environment as a result of increased use of renewable energy sources in the sector of transportation, according to the simulation results. |
| Wang *et al*, 2011. [15] | WECs | Simulation without Validation | The simulation results show that by optimally redistributing the PHEV charging load, the system's total operating costs can be drastically reduced. |
| Munkhammar *et al.*, 2013. [16] | Solar PV | Stochastic modeling Approach | The addition of a PEV increases both individual and aggregate self-consumption of photovoltaic energy, but the benefit is limited by the low coincidence between the photovoltaic energy production pattern and the PEV charging pattern. |
| Denholm *et al.*, 2016. [17] | Solar PV | Simulation using REFlex model | In addition to achieving a reasonable charging station planning scheme, simulation results showed that the developed model and method could reduce network loss and improve voltage profile. |
| Ribberink and Entchev, 2014. [18] | Micro CHP | Simulation using the Transient Energy System Simulation Tool (TRNSYS) Program | The study concluded that, depending on the degree of adoption of each technology, PV could meet all of the increased capacity needs associated with the deployment of PHEVs, while PHEVs could largely offset any potential decrease in PV generation. |
| Sedghi *et al.*, 2015. [19] | WECs | Point estimate method | According to the study's findings, a high photovoltaic capacity could |

| | | | |
|---|---|---|---|
| | | and Tabu search algorithm | only partially meet transportation demand if the charge is out of control. Non-photovoltaic generation would require a significant increase in the late afternoon in this scenario. |
| Chu *et al.,* 2015. [20] | Solar PV | Simulation without validation | The findings suggest that active distribution networks can benefit from battery units, which are more advantageous and adaptable to changing conditions than capacitor banks in passive networks. By optimising the schedule, costs and risks should be reduced to the greatest extent possible. |
| Singh *et al.,* 2016. [21] | Solar PV | Simulation without Validation | The case study simulation results show that if the smart charging strategy is implemented, the environmental goals of reducing carbon dioxide emissions can be met with a high market share for electric vehicles and a supply of electricity derived entirely from renewable energy sources. |
| Pearre and Swan, 2016. [22] | Hybrid WECs-Tidal system | Simulation | The data analysis revealed a fivefold difference in daily average PV energy production between summer and winter months. To provide power during the winter and consume excess PV energy during the summer, an EV-PV charger must be connected to the grid. |
| Angrisani *et al.,* 2016. [23] | Solar PV | Modelling using TRNSYS | The effects of three different pricing policies on the relationship between renewable electricity generation and export transmission constraints were investigated in this study. The findings demonstrated the efficacy of |

| | | | |
|---|---|---|---|
| | | | these grid management strategies: A 10% increase in EV adoption could benefit from the additional transmission capacity provided by such charging algorithms, which could range from 0.6-3 MW. |
| Cortés *et al.,* 2018. [24] | Hybrid Solar PV-BESS | Simulation using MATLAB optimization framework | The solar-powered system used less primary energy and produced less $CO_2$ than the standard structure, which included a natural gas-fired boiler, a diesel vehicle, and an electric chiller. This demonstrates the cost-effectiveness of a direct current-charging solar energy system. |
| Tooryan *et al.,* 2022. [25] | Solar PV and BESS | Real-time performance Analysis | The results based on the developed Control Protocol show that homes with BESS do not use grid electricity during peak times for electric prices when switching between the control law corresponds to both modes V2H (vehicle-to-home) and H2V (home-to-vehicle). |
| Sinha and Chandel 2017. [26] | Hybrid Solar PV-WECs | Modelling using PLEXOS software | The study discovered that by charging itself with excess solar energy and discharging itself during peak demand periods, the battery energy storage system could mitigate the effects of solar intermittency and energy demand fluctuations. |
| Novoa and Brouwer, 2018. [27] | Solar PV and BESS | Performance analysis using control algorithm | According to the study, even without V2G technology, adding EVs to the grid can have a number of advantages. It has been demonstrated that charging EVs during the day can reduce VRE curtailment, the average annual marginal cost of electricity |

| | | | |
|---|---|---|---|
| | | | production, and the need for grid-connected storage by up to 13%. However, if uncontrolled evening charging occurs, the demand for grid-connected storage may increase. |
| Madeleine *et al.*, 2018. [28] | Hybrid solar PV- WECs-Hydro | Modelling using SPLAT (Systems Planning Test) | The results showed that the control algorithms could effectively use the battery to shift the peak load of the nanogrid, and that the nanogrid could completely offset the loads associated with EV daily charging. |
| Odoi-Yorke *et al.*, 2022. [29] | Solar PV-Biogas hybrid | Simulation without validation | The study's findings suggest that decentralization and variable renewable energy penetration are effective tools for reducing greenhouse gas emissions. Vehicle-to-grid charging optimization lowers system costs by eliminating the need for additional storage infrastructure. To meet demand spikes, a high peaking capacity is required if electric vehicle charging is not actively managed. |
| Kiran *et al.*, 2021. [30] | Hybrid solar PV- WECs | Modelling and Simulation | With an electric vehicle market penetration index of 4%, the island's energy consumption is estimated to be 46,327 kWh/month; fortunately, the island generates twice as much biogas as is required to provide the required 16,200 kWh. The findings show that the system is viable for powering homes and EVs. |
| Karmaker *et al.*, 2018. [31] | Hybrid solar PV- biogas generators | Modelling using Hybrid Optimization of Multiple | This study's findings conclusively demonstrate the efficacy of the proposed strategy. The findings show that even when RES energy generation is low, EVs can still |

| | | | |
|---|---|---|---|
| | | Energy Renewables | support DC energy consumption efficiently. |
| Hasan and Rakhshani, 2019. [32] | Solar PV | Modelling using GAMS software | As this study shows, hybrid power systems significantly reduce harmful emissions. The charging station has been determined to be suitable for V2G energy export. |
| Krishan and Suhag, 2019. [33] | Solar PV-WECs-BESS-<br>Heat pump | Dynamic simulation using TRNSYS environment | The achieved charging-discharging pattern for V2G systems and energy shifting can be used to reduce the financial burden of usage when addressing the intermittent nature of a solar PV electricity system. |
| Salama and Vokony, 2020. [34] | WECs | Simulation using GAMS software | The study concludes that the addition of BESS improves the system's weekly average dependability using a variety of reliability indicators. According to the findings, average system reliability is determined by system power and configuration, whereas uncertainty is influenced by the time-varying nature of loads and renewable energy sources. |
| Park, 2020. [35] | WECs-BESS | Modelling using GAMS/CPLEX | The simulation shows that increasing the capacity of all available resources lowers daily operational costs. The findings validated the building's ability to meet demand while disconnected from the grid, as well as its ability to operate without a single component. |
| Khan *et al.*, 2020. [36] | Solar PV | Mathematical modelling using Techno Economic Environmental Optimization | According to the study's findings, removing the battery energy storage system would increase reinforcement by 185%. Limiting the reinforcement to 150% increases |

| | | | |
|---|---|---|---|
| | | | the battery's power and capacity significantly to 501 kW and 2683 kWh, respectively. |

## 5. Conclusion

The paper presents the study of hybrid solar-PV-wind energy system. Wind and solar power have been used to supply all or part of the energy needs of a private home, farm house, small business, educational institution, or apartment building, depending on the site's peculiarities. This has improved dependability while reducing reliance on a single vendor. In contrast to the various modes of operation of the individual generators, this allows us to increase the overall efficiency of the system.

## References

[1] O.M. Babatunde, J.L. Munda, Y. Hamam, Hybridized off-grid fuel cell/wind/solar PV/battery for energy generation in a small household: A multi-criteria perspective, *International Journal of Hydrogen Energy*, 47(10), (2022) 6437-6452. https://doi.org/10.1016/j.ijhydene.2021.12.018

[2] M. López, N. Rodríguez, G. Iglesias, combined floating offshore wind and solar PV, *Journal of Marine Science and Engineering*, 8(8), (2020) 576. https://doi.org/10.3390/jmse8080576

[3] G.B. Kumar, Optimal power point tracking of solar and wind energy in a hybrid wind solar energy system, *International Journal of Energy and Environmental Engineering*, 13(1), (2022) 77-103. http://dx.doi.org/10.1007/s40095-021-00399-9

[4] J. Ferrero Bermejo, J.F. Gómez Fernández, F. Olivencia Polo, A. Crespo Márquez, A review of the use of artificial neural network models for energy and reliability prediction. A study of the solar PV, hydraulic and wind energy sources, *Applied Sciences*, 9(9), (2019) 1844. https://doi.org/10.3390/app9091844

[5] T. Sarkar, A. Bhattacharjee, H. Samanta, K. Bhattacharya, H. Saha, Optimal design and implementation of solar PV-wind-biogas-VRFB storage integrated smart hybrid microgrid for ensuring zero loss of power supply probability, *Energy conversion and management*, 191, (2019) 102-118. https://doi.org/10.1016/j.enconman.2019.04.025

[6] S. Puchalapalli, S.K. Tiwari, B. Singh, P.K. Goel, A microgrid based on wind-driven DFIG, DG, and solar PV array for optimal fuel consumption. *IEEE Transactions on Industry Applications*, 56(5), (2020) 4689-4699. https://doi.org/10.1109/TIA.2020.2999563

[7] M. Subramaniam, C. Rambabu, G. Chandrasekaran, N.S Kumar, A Traffic Density-Based Congestion Control Method for VANETs. *Wireless Communications and Mobile Computing, 2022.* (2022). https://doi.org/10.1155/2022/7551535

[8] G.S Patil, A. Mulla, S. Dawn, T.S Ustun, Profit Maximization with Imbalance Cost Improvement by Solar PV-Battery Hybrid System in Deregulated Power Market. *Energies*, 15(14), (2022). 5290. https://doi.org/10.3390/en15145290

[9] P.R. Karthikeyan, G. Chandrasekaran, N.S. Kumar, E. Sengottaiyan, P. Mani, D.T. Kalavathi, V. Gowrishankar, IoT based moisture control and temperature monitoring in smart farming. In *Journal of Physics: Conference Series IOP Publishing,* 1964(6), (2021) 062056. http://dx.doi.org/10.1088/1742-6596/1964/6/062056

[10] G. Chandrasekaran, N.S Kumar, P.R. Karthikeyan, K. Vanchinathan, N. Priyadarshi, B. Twala, Test Scheduling and Test Time Minimization of System-on-Chip Using Modified BAT Algorithm. *IEEE Access,* 10, (2022) 126199-126216. https://doi.org/10.1109/ACCESS.2022.3224924

[11] D.B Carvalho, E.C Guardia, J.W.M. Lima, Technical-economic analysis of the insertion of PV power into a wind-solar hybrid system. *Solar Energy*, 191, (2019) 530-539. https://doi.org/10.1016/j.solener.2019.06.070

[12] G. Chandrasekaran, P.R. Karthikeyan, N.S. Kumar, V. Kumarasamy, Test scheduling of system-on-chip using dragonfly and ant lion optimization algorithms. *Journal of Intelligent & Fuzzy Systems*, *40*(3), (2021) 4905-4917. http://dx.doi.org/10.3233/JIFS-201691

[13] N.S Kumar, G. Chandrasekaran, J. Thangavel, N. Priyadarshi, M.S Bhaskar, M.G Hussien, M.M. Ali, A Novel Design Methodology and Numerical Simulation of BLDC Motor for Power Loss Reduction. *Applied Sciences*, *12*(20), (2022)10596. https://doi.org/10.3390/app122010596

[14] M. Pantoš, Stochastic optimal charging of electric-drive vehicles with renewable energy. *Energy*, 36(11), (2011) 6567-6576. https://doi.org/10.1016/j.energy.2011.09.006

[15] X. Wang, N. Kannan, C. Santhi, S.R. Potter, J.R. Williams, J.G Arnold, Integrating APEX output for cultivated cropland with SWAT simulation for regional modelling, *Transactions of the ASABE*, 54(4), (2011) 1281-1298. http://dx.doi.org/10.13031/2013.39031

[16] J. Munkhammar, P. Grahn, J. Widén, Quantifying self-consumption of on-site photovoltaic power generation in households with electric vehicle home charging, *Solar energy*, 97, (2013) 208-216. https://doi.org/10.1016/j.solener.2013.08.015

[17] P. Denholm, R. Margolis, (2016) *Energy storage requirements for achieving 50% solar photovoltaic energy penetration in California* (No. NREL/TP-6A20-66595). *National Renewable Energy Lab,* (NREL), United States.

[18] H. Ribberink, E. Entchev, Exploring the potential synergy between micro-cogeneration and electric vehicle charging. *Applied thermal engineering*, 71(2), (2014) 677-685. https://doi.org/10.1016/j.applthermaleng.2013.10.051

[19] M. Sedghi, A. Ahmadian, M. Aliakbar-Golkar, Optimal storage planning in active distribution network considering uncertainty of wind power distributed generation, *IEEE Transactions on Power Systems*, 31(1), (2015) 304-316. https://doi.org/10.1109/TPWRS.2015.2404533

[20] Y. Chu, B. Urquhart, S.M. Gohari, H.T. Pedro, J. Kleissl, C.F. Coimbra, Short-term reforecasting of power output from a 48 MWe solar PV plant, *Solar Energy, 112*, (2015) 68-77. https://doi.org/10.1016/j.solener.2014.11.017

[21] B. Singh, C. Jain, S. Goel, A. Chandra, K. Al-Haddad, A multifunctional grid-tied solar energy conversion system with ANF-based control approach, *IEEE Transactions on Industry Applications*, 52(5), (2016) 3663-3672. https://doi.org/10.1109/TIA.2016.2582141

[22] N.S. Pearre, L.G Swan, Electric vehicle charging to support renewable energy integration in a capacity constrained electricity grid, *Energy conversion and management*, *109*, (2016) 130-139. https://doi.org/10.1016/j.enconman.2015.11.066

[23] G. Angrisani, E. Entchev, C. Roselli, M. Sasso, F. Tariello, W. Yaïci, Dynamic simulation of a solar heating and cooling system for an office building located in Southern Italy, *Applied Thermal Engineering*, 103, (2016) 377-390. https://doi.org/10.1016/j.applthermaleng.2016.04.094

[24] A. Cortés, J. Mazón, J. Merino, Strategy of management of storage systems integrated with photovoltaic systems for mitigating the impact on LV distribution network. *International Journal of Electrical Power & Energy Systems*, 103, (2018) 470-482. https://doi.org/10.1016/j.ijepes.2018.06.012

[25] F. Tooryan, H. Hassanzadeh Fard, V. Dargahi, S. Jin, A cost-effective approach for optimal energy management of a hybrid CCHP microgrid with different hydrogen production considering load growth analysis, *International Journal of Hydrogen Energy*, 47(10), (2022) 6569-6585. https://doi.org/10.1016/j.ijhydene.2021.12.036

[26] S. Sinha, S.S. Chandel, Improving the reliability of photovoltaic-based hybrid power system with battery storage in low wind locations, *Sustainable Energy Technologies and Assessments*, 19, (2017) 146-159. https://doi.org/10.1016/j.seta.2017.01.008

[27] L. Novoa, J. Brouwer, Dynamics of an integrated solar photovoltaic and battery storage nanogrid for electric vehicle charging, *Journal of Power Sources*, 399, (2018) 166-178. https://doi.org/10.1016/j.jpowsour.2018.07.092

[28] M.H. Jahangir, S. Fakouriyan, M.A.V. Rad, H. Dehghan, Feasibility study of on/off grid large-scale PV/WT/WEC hybrid energy system in coastal cities: A case-based research, *Renewable Energy*, 162, (2020) 2075-2095. https://doi.org/10.1016/j.renene.2020.09.131

[29] F. Odoi-Yorke, S.Abaase, M. Zebilila, L. Atepor, Feasibility analysis of solar PV/biogas hybrid energy system for rural electrification in Ghana, *Cogent Engineering*, 9(1), (2022) 2034376. https://doi.org/10.1080/23311916.2022.2034376

[30] K.B. Kiran, M.S Indira, R. Nagaraja, Mathematical modeling and evaluation of performance characteristics of a hybrid solar PV and wind energy system, *Journal of Applied Science and Engineering*, *25*(4), (2021) 685-697. https://doi.org/10.6180/jase.202208_25(4).0014

[31] A.K Karmaker, M.R. Ahmed, M.A. Hossain, M.M. Sikder, Feasibility assessment & design of hybrid renewable energy based electric vehicle charging station in Bangladesh, *Sustainable cities and society*, 39, (2018) 189-202. https://doi.org/10.1016/j.scs.2018.02.035

[32] H. Mehrjerdi, E. Rakhshani, Vehicle-to-grid technology for cost reduction and uncertainty management integrated with solar power. *Journal of Cleaner Production*, 229, (2019) 463-469. https://doi.org/10.1016/j.jclepro.2019.05.023

[33] O.Krishan, & S. Suhag, Techno-economic analysis of a hybrid renewable energy system for an energy poor rural community, *Journal of Energy Storage*, 23,(2019)305-319. https://doi.org/10.1016/j.est.2019.04.002

[34] H.S. Salama, I. Vokony, Comparison of different electric vehicle integration approaches in presence of photovoltaic and superconducting magnetic energy storage systems. *Journal of Cleaner Production*, 260, (2020) 121099. https://doi.org/10.1016/j.jclepro.2020.121099

[35] H. Park, Generation capacity expansion planning considering hourly dynamics of renewable resources, *Energies*, 13(21), (2020) 5626. https://doi.org/10.3390/en13215626

[36] A. Paladin, R. Das, Y. Wang, Z. Ali, R. Kotter, G. Putrus, R. Turri, Micro market-based optimisation framework for decentralised management of distributed flexibility assets, *Renewable Energy*, 163, (2021) 1595-1611. https://doi.org/10.1016/j.renene.2020.10.003

## Funding

No funding was received for conducting this study.

## Conflict of interest

The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

## About The License