International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-10, Issue-02, May 2024

HOMER-Assisted Optimization of Solar-to-Fuel Grid Integration

A. Pooja Soni, PhD Scholar (Electrical Engineering Depart.), College of Technology & Engineering, MPUAT, Udaipur, INDIA, poojaswarnakar93@gmail.com

B. Vikramaditya Dave, HOD (Electrical Engineering Depart.), College of Technology & Engineering, MPUAT, Udaipur, INDIA, vdaditya1000@gmail.com

Abstract **This paper presents the simulation, modeling, and optimization of a Grid-tied system tailored for a commercial building. The primary aim is to design a system that efficiently meets the electricity needs, prioritizing renewable energy sources, minimizing surplus power, reducing energy costs, and cutting greenhouse gas emissions. Through simulation and optimization techniques, the study evaluates various configurations of a hybrid solar photovoltaic (PV) and fuel cell system. The findings reveal that integrating solar PV with a fuel cell, alongside a solar-based electrolyzer for hydrogen production and employing cycle charging control, yields optimal performance. Specifically, the hybrid system generates 68% of its power from solar PV and 28% from the fuel cell.**

***Keywords* —Solar PV, Fuel cell, Electrolyzer, Microgrid, Optimization, Modeling.**

I. INTRODUCTION

Grid-tied solar PV fuel cell systems marks a significant advancement in sustainable energy solutions. These systems integrate solar photovoltaic (PV) technology with fuel cell technology, offering a hybrid approach to electricity generation. In grid-tied configurations, these systems are connected to the main utility grid, allowing for seamless integration and interaction with the existing infrastructure.

Grid-tied solar PV fuel cell systems leverage the complementary benefits of both solar PV and fuel cell technologies. Solar PV harnesses energy from sunlight to generate electricity, while fuel cells convert chemical energy from fuels like hydrogen into electricity through electrochemical reactions. By combining these technologies, grid-tied systems can maximize energy production and enhance overall system efficiency.

One of the key advantages of grid-tied solar PV fuel cell systems is their ability to contribute clean energy to the grid while also drawing supplementary power from the grid when needed. This dynamic interaction enables efficient energy management, ensuring a reliable and stable electricity supply for consumers.

Moreover, grid-tied systems facilitate the integration of renewable energy sources into the existing grid infrastructure, helping to reduce dependence on fossil fuels and mitigate greenhouse gas emissions. They also offer potential economic benefits through mechanisms such as net metering, allowing consumers to offset their electricity bills by exporting excess energy to the grid.

A microgrid power system encompasses a discrete energy framework comprising various distributed energy sources, including renewables such as wind, solar, geothermal, biomass, hydro, and ocean-based energy. It also incorporates generators fueled by both traditional and alternative energy sources, energy storage systems, loads catering to residential, commercial, and industrial needs, power conditioning units like inverters and converters, and demand management and control systems. This microgrid energy setup is designed to function either in parallel with or independently from the main utility grid, offering local control and enhancing energy independence. Such locally managed microgrid systems contribute to energy resilience by providing backup during utility grid disruptions caused by severe weather events or natural disasters, thereby ensuring a more reliable energy supply and reducing transmission losses. Essentially, microgrids serve as modern, small-scale centralized electricity systems, aligning with community objectives such as diversifying energy sources, reducing carbon emissions through renewable integration, ensuring energy reliability, resilience against power outages, and cost reduction.

Hybrid PV (photovoltaic) and fuel cell systems, augmented with hydrogen tanks, electrolyzers, converters, and integrated into electric loads and grid systems, marks a significant stride towards a more sustainable and versatile energy landscape.

Hybrid PV and fuel cell systems combine the strengths of solar PV technology, which converts sunlight into electricity, with fuel cell technology, which generates electricity through electrochemical reactions. By integrating

 DOI : 10.35291/2454-9150.2024.0123 **© 2024, IJREAM All Rights Reserved.**

these technologies, hybrid systems can capitalize on the intermittent nature of solar power and the consistent output of fuel cells, ensuring a more reliable and consistent energy supply.

Incorporating hydrogen tanks and electrolyzers into these hybrid systems adds a new dimension of energy storage and flexibility. Excess electricity generated by the PV panels can be used to produce hydrogen through electrolysis, which can then be stored in tanks for later use in fuel cells or other applications. This enables the storage of renewable energy for times when sunlight is not available, thereby enhancing the overall efficiency and reliability of the system. Hydrogen fuel cells represent a cutting-edge technology in the realm of clean energy. These devices operate through an electrochemical reaction between hydrogen and oxygen, emitting only water vapor and heat as byproducts, thus making them exceptionally environmentally friendly with zero greenhouse gas emissions during operation. Renowned for their high efficiency in converting chemical energy directly into electricity, fuel cells find application across diverse sectors, from stationary power generation for buildings and industrial facilities to powering vehicles, buses, trains, and even aircraft. Their reliability in delivering continuous power, coupled with scalability to meet varying energy demands, underscores their versatility. Moreover, fuel cells operate quietly, ensuring minimal noise pollution in residential and indoor environments. With a longer lifespan compared to traditional batteries and combustion engines, fuel cell systems require minimal maintenance. Additionally, their ability to utilize different fuels, including hydrogen, natural gas, methanol, or biomass-derived hydrogen, provides flexibility in energy sources. However, challenges such as the cost of hydrogen production, infrastructure development for storage and distribution, and ongoing technological advancements to enhance efficiency and reduce manufacturing costs, must be addressed to unlock their full potential in the global energy landscape.

II. LITERATURE REVIEW

Numerous studies in the literature explore microgrid power systems. For instance, one study integrated renewable sources like micro-hydro (MHP) and photovoltaic (PV) systems into a microgrid model connected to the grid [1]. Results demonstrated optimal performance of power plants utilizing renewable sources, with the highest capacity MHP microgrid exhibiting the lowest energy costs, significant CO2 emissions reduction, and the largest proportion of renewable energy. However, these outcomes necessitated substantial initial capital investment. Another study proposed a biomass-based PV power plant to supply electricity to agricultural wells [2]. Findings suggested that combining PV and biomass systems could create a reliable and cost-effective hybrid energy solution. Previous investigations have also explored hybrid technology combinations for electricity generation from various renewable resources, including small-scale hydropower, solar PV systems, wind turbines, bio-diesel generators, and fuel cells [3]–[9].

Simulation, modeling and optimization using HOMER software and Simulink [10]–[17] were also used to identify the optimal off-grid options. The results show that a hybrid combination of renewable energy generators at an off-grid location can be a cost-effective alternative to grid extension. Micro-power optimization model was used in [10] to design renewable energy-based micro grid system: solar-biomass hybrid system for the electrification of the city of Sharjah. Dynamic simulation was used in [12] to design PV-dieselbattery off grid power system. A switched model predictive control for energy dispatching of PV-diesel-battery hybrid power system was investigated in [13]. Simulink was used, in [14], for economic analysis and environmental impacts of hybrid PV-diesel-battery systems for remote villages. Different control strategies were used, in [15], and [16], for modeling hybrid PV-wind-engine-battery and PV-diesel-battery hybrid power systems, respectively.

III. PROPOSED METHODOLOGY

This research aims to explore possibility of usage of Hybrid Renewable Energy System for a Grid-tied Solar PV- Fuel cell based micro power system. The proposed system will be designed for an area with a particular load demand. In Hybrid Power Systems, the optimal size of each system component is a complex task and involves several variables. So the aim is to have a good relation between performance and cost, also optimally designed hybrid system should be cost effective and reliable.

The concept of injecting photovoltaic power into utility grid has earned widespread acceptance in these days of renewable energy generation & distribution. Grid-connected inverters have evolved significantly with high diversity. Efficiency, size, weight, reliability etc. have all improved significantly with the development of modern and innovative inverter configurations and these factors have influenced the cost of producing inverters. Amongst the several fuel cells types used, hydrogen has become the most efficient and reliable fuel type. As hydrogen has become an important intermediary for the energy transition and it can be produced from renewable energy sources, re-electrified to provide electricity and heat, as well as stored for future use.

An on-grid or grid-tied solar system is a system that works along with the grid. This means that any excess or deficiency of power can be fed to the grid through net metering. Many residential users are opting for an on-grid

 DOI : 10.35291/2454-9150.2024.0123 © 2024, IJREAM All Rights Reserved.

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 **Vol-10, Issue-02, May 2024**

solar system as they get a chance to enjoy credit for the excess power their system produces and save on their electricity bills. You will always have power either from the solar system or from the grid. They do not have batteries.

In this study, HOMER optimization model will be used. HOMER is capable to model and simulate a considerable number of system combinations, in order to achieve the best technical and economical results for a system. Input data required for HOMER are Meteorological data, Load profile, Economic data such as capital, and replacement cost, Fuel price, price of transaction electricity with the grid etc. Also depending upon climatic condition and renewable energy resources available, suitable data will be collected. Large numbers of options are available for different sizes of the components to be used. To fulfill that load demand of selected area different combination of hybrid renewable sources will be studied. Out of several possible combinations most economic and environmental friendly combination will be selected. This selection is made with the help of simulation results obtained from HOMER software.

HOMER is very popular and commercial software developed by National Renewable Energy Laboratory (NREL)/USA. This software is used for designing and planning HRES; evaluate technical and financially feasible options for off-grid and on-grid power systems. Various components of HRES can be modeled in HOMER such as wind turbines, solar PV array, fuel cells, small hydropower, biomass, converter, storage system, batteries and diesel/conventional generators. Inputs to the HOMER software are meteorological data such as wind speed, solar insolation, temperature etc., load profile of the area, technical details of generator, capital, replacement and operational & maintenance costs of components, controls and dispatch strategy. HOMER can perform simulation, optimization and sensitivity analysis of the HRES

Grid Tied Systems is connected to a larger independent grid typically the public electricity grid and feeds energy directly into the grid. The feeding of electricity into the grid requires the transformation of DC into AC by a synchronizing grid-tie inverter (also called grid interactive inverter).

IV. MODEL

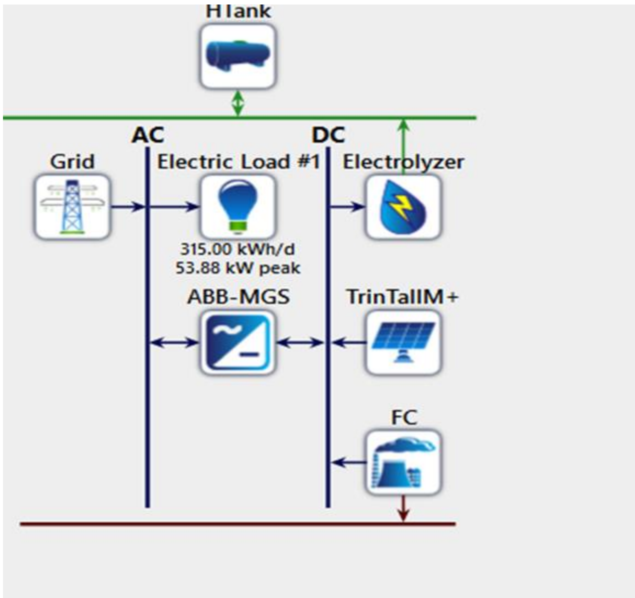

Fig 1. HRES MODEL

Component	Capital Cost (₹)	Replacement Cost (₹)	O &M Cost (₹)	Lifetime (Years)
Solar PV	₹3,803,203.12	0	0	25
Generic Fuel Cell	₹45,000.00	₹57,083.73	₹15,365.65	50000 Hours
Hydrogen Tank	₹250,000.00	0	₹6,463.76	25
Converter	₹4,800.00	₹1,484.96	₹6,463.76	15
Grid	0	0	₹1,154,887.06	-

Table 1. Cost of the components

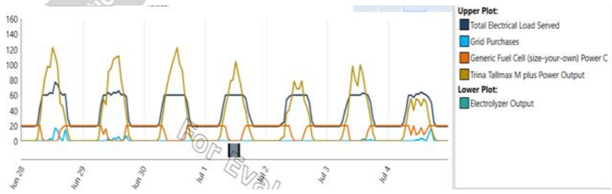

Fig 2. Output Graph

V. RESULTS

Results of HOMER Pro software HOMER software aims to minimize the cost of energy (COE) both in finding the optimal system configuration and in operating the system; economics play a crucial role in the simulation. The parameter considered to compare the economics of different configuration is the cost of energy (COE), and the total NPC is taken as the economic figure of merit. HOMER simulates the operation of a system by making energy balance calculations in each hourly time step of the year. For each time step, HOMER compares the electric demand in that time step to the energy that the system can supply in that time step. Then, it calculates the flow of

 DOI : 10.35291/2454-9150.2024.0123 © 2024, IJREAM All Rights Reserved.

energy to and from each component of the system. HOMER performs these energy balance calculations for each system configurations that were considered. It then determines whether a configuration is feasible, i.e., whether it can meet the electric demand under the specified conditions, and estimates the cost of installing and operating the system over the lifetime of the project. After simulating all of the possible system configurations, HOMER displayed a list of configurations sorted by net present cost (NPC) and cost of energy (COE), which can be used to compare the different system design options. The NPC of a component is the net present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER Pro software facilitates non-linear optimization for designing HRES. A proposed grid-connected solar-wind-biogas system for the Electrical Engineering Department of CTAE, Udaipur, Rajasthan, includes a 84.5 KW solar PV system, 15 KW fuel cell.

VI. Conclusion

Increasing global interest in renewable energy generation is driven by concerns over the finite nature of fossil fuel resources. Coal and oil production are expected to peak soon, followed by a decline, while uranium production is forecasted to reach its zenith by 2035. Recycling nuclear fuel presents risks, making renewable energy systems (RES) an attractive alternative. RES, such as solar and wind, offer environmentally friendly solutions, devoid of greenhouse gas emissions, and are cost-effective compared to fossil fuels.

Hybrid Renewable Energy Systems (HRES), integrating renewable sources with fossil fuels, offer a robust solution. However, designing optimal HRES requires considering environmental factors and selecting suitable renewable sources. Grid-connected HRES, especially in urban areas, reduce dependency on the grid and lower emissions. Comparing results, the GWO cuckoo search program outperforms HOMER, converging faster and providing superior designs with lower NPC, COE, and emissions. This superiority arises from GWO's-Cuckoo use of biologically inspired operators for optimization, unlike HOMER, which relies solely on energy balance calculations.

References

[1] R. Nazir, H.D. Laksono, E.P. Waldi, E. Ekaputra and P. Coveria, “Renewable Energy Sources Optimization: A Micro-Grid Model Design,” *Energy Procedia*, vol. 52, pp. 316–327, 2014.

[2] A. Heydari and A. Askarzadeh, “Optimization of a biomass-based photovoltaic power plant for an off-grid application subject to loss of power supply probability concept, *Applied Energy*, vol. 165, pp. 601– 611, 2016.

[3] R. Sen and S.C. Bhattacharyya, “Off-grid electricity generation with renewable energy technologies in India: An application of HOMER,” *Renewable Energy*, vol. 62, pp. 388–398, 2014.

[4] H. Lan, S. Wena,Y-Y. Hong, D. C. Yu, and L. Zhang, “Optimal sizing of hybrid PV/diesel/battery in ship power system,” *Applied Energy*, vol. 158, pp. 26–34, 2015.

[5] L. K. Gan, J. K.H. Shek, and M. A. Mueller, “Hybrid wind– photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland,” *Energy Conversion and Management*, vol. 106, pp.479–494, 2015.

[6] H. Tazvinga, X. Xia, and J. Zhang, “Minimum cost solution of photovoltaic–diesel–battery hybrid power systems for remote consumers,” *Solar Energy*, vol. 96, pp. 292–299, 2013.

[7] A. Merabet, K. Ahmed, H. Ibrahim, R. Beguenane, and A. Ghias, “Energy management and control system for laboratory scale microgrid based wind-PV-battery,” *IEEE Trans. Sustain. Energy*, vol. 8, no. 1, pp. 145–154, 2017.

[8] A. Islam, A. Merabet, R. Beguenane, H. Ibrahim, “Power management strategy for solar-wind-diesel stand-alone hybrid energy system”, *Int. J. Electrical, Computer, Electronics and Communication Engineering*, vol. 8, no. 6, pp. 831–835, 2014.

[9] V. Rajasekaran, A. Merabet, H. Ibrahim, R. Beguenane, J. S. Thongam, “Control system for hybrid wind diesel based microgrid”, in *IEEE Electrical Power and Energy Conference*, Halifax, Canada, pp. 1–6, 2013.

[10] C. Ghenai, and I. Janajreh, “Design of Solar-Biomass Hybrid Microgrid System in Sharjah,” *Energy Procedia*, vol. 103, pp. 357–362, 2016.

[11] T. Lambert, P. Gilman, and P. Lilienthal, “Micropower system modeling with HOMER,” *Chap. 15 in Integration of Alternative Sources of Energy*, by F. A. Farret and M. G. Simoes, John Wiley & Sons, 2006.

[12] S. Yilmaz, H. R. Ozcalikb, M. Aksua, and C. Karapınara, “Dynamic simulation of a PV-diesel-battery hybrid plant for off grid electricity supply,” *Energy Procedia*, vol. 75, pp. 381–387, 2015.

[13] B. Zhu, H. Tazvinga, and X. Xia, “Switched model predictive control for energy dispatching of a photovoltaic-diesel-battery hybrid power system,”

 DOI : 10.35291/2454-9150.2024.0123 © 2024, IJREAM All Rights Reserved.

IEEE Trans. Control Syst. Technol., vol. 23, no. 3, pp. 1229– 1236, 2015.

[14] R. W. Wies, R. A. Johnson, A. N. Agrawal, and T. J. Chubb, "Simulink model for economic analysis and environmental impacts of a PV with diesel-battery system for remote villages," *IEEE Trans. Power Syst.*, vol. 20, no. 2, pp. 692–700, 2005.

[15] S. G. Sigarchiana, A. Malmquista, and T. Franssona, "Modeling and control strategy of a hybrid PV/Wind/Engine/Battery system to provide electricity and drinkable water for remote applications", *Energy Procedia*, vol. 57, pp. 1401–1410, 2014.

[16] B. Zhu, H. Tazvinga, and X. Xia "Model predictive control for energy dispatch of a photovoltaic-diesel-battery hybrid power system," *Proc. 19th World Congress The International Federation of Automatic Control*, Cape Town, South Africa, pp. 11135–11140, 2014.

[17] Vivas, F.; De Las Heras, A.; Segura, F.; Andújar, J.M. A review of energy management strategies for renewable hybrid energy systems with hydrogen backup. Renew. Sustain. Energy Rev. 2018, 82, 126–155.

[18] Ammari, C.; Belatrache, D.; Touhami, B.; Makhloufi, S. Sizing, optimization, control and energy management of hybrid renewable energy system—A review. Energy Built Environ. 2022, 3, 399–411.

[19] Modu, B.; Abdullah, P.; Bukar, A.L.; Hamza, M.F. A systematic review of hybrid renewable energy systems with hydrogen storage: Sizing, optimization, and energy management strategy. Int. J. Hydrogen Energy 2023, 48, 38354–38373.

[20] Khan, A.A.; Minai, A.F.; Pachauri, R.K.; Malik, H. Optimal Sizing, control, and Management Strategies for Hybrid Renewable Energy Systems: A Comprehensive Review. Energies 2022, 15, 6249.

[21] Chang, C. Multi-choice goal programming model for the optimal location of renewable energy facilities. Renew. Sustain. Energy Rev. 2015, 41, 379–389.

[22] Reddy, S.S.; Momoh, J.A. Realistic and transparent optimum scheduling strategy for hybrid power system. IEEE Trans. Smart Grid 2015, 6, 3114–3125.

[23] 7. Abbes, D.; Martinez, A.; Champenois, G. Life cycle cost, embodied energy and loss of power supply probability for the optimal design of hybrid power systems. Math. Comput. Simul. 2014, 98, 46–62.

[24] . Roy, P.; He, J.; Liao, Y. Cost minimization of Battery-Supercapacitor hybrid energy storage for hourly dispatching Wind-Solar hybrid power system. IEEE Access 2020, 8, 210099–210115.

[25] . Sawle, Y.; Gupta, S.; Bohre, A.K. Techno-economic scrutiny of HRES through GA and PSO technique. Int. J. Renew. Energy Technol. 2018, 9, 84.

[26] Muleta, N.; Badar, A.Q.H. Designing of an optimal standalone hybrid renewable energy micro-grid model through different algorithms. J. Eng. Res. 2023, 11, 100011.

 DOI : 10.35291/2454-9150.2024.0123 © 2024, IJREAM All Rights Reserved.