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Assessment of a Stand-alone Hybrid PV-Hydrogen Based Electric Vehicle Charging Station Model Using HOMER

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Abstract: Amongst all introduced renewable resources, hydrogen is one of the most encouraging contenders for meeting energy demands. Hydrogen is the most eco-friendly fuel. Hydrogen is a clean and effective energy carrier, and a hydrogen-based economy is extensively considered as a practical solution for energy security and sustainability in the future. Due to its richness and diverse production resources, hydrogen, is becoming an increasingly possible clean and green alternative for energy storage and transportation. As the existing demand for energy soars, hydrogen has grown into the most important source. This article introduces a techno-economic assessment of a novel stand-alone hybrid PV-hydrogen energy-based charging station in Jamshoro, Sindh, Pakistan, to meet daily charging demand for plug-in Electric Vehicles (EV). The proposed design is modelled and simulated using HOMER software to investigate the conceptual system. The hybrid PV-hydrogen-battery energy system was witnessed to be more cost-effective than the PV-hydrogen energy system, with a unit cost of electricity of 0.379 Rs/kWh versus 0.432 Rs/kWh for the PV-hydrogen energy system. With a daily load demand of 1750 kWh/day, the simulation results showed that total electricity production consists of power generated by solar PV (89.4%) and fuel-cells (10.6%). These outcomes indicate that a renewable-energy-powered EV charging station is cost-effective for the proposed site.

Keywords: Hydrogen, techno-economic, charging station, HOMER.

1. Introduction

The continuous expansion of world population and economy, linked with rapid urbanization has stemmed in a historic rise in the demand for energy [1]. The old-fashioned energy supply standard is centered on hydrocarbon (fossil fuel) energy supplies, which are exhausted and restricted by geographical scattering and extraction complexity [2]. Since the industrial revolution, the methods by which individuals have used fossil fuels as our leading source of energy have resulted in a

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tremendous increase in the concentration of CO_2 and other greenhouse gases (GHG) in our environment, which is the main reason of global warming [3]. As an outcome, decarbonization of the energy supply due to the use of substitute clean, sustainable, and renewable energy is crucial for future energy sustainability and security [4].

Renewable Energy (RE) resources will indeed be critical in the transition to a clean, long-term energy system [5]. The fluctuating and intermittent character of these supplies is the fundamental barrier in shifting to 100% REs [6]. This necessitates technical adaptation, particularly in terms of balancing shifting energy supply and demand [7]. Energy storage systems (ESS), on the other hand, offer a practical alternative for storing power when supply exceeds demand and converting that collected energy back up to the grid while demand surpasses supply.

The reversible fuel cell (RFC), which can harvest hydrogen and stockpile it for upcoming requirements as a fuel or as a latent energy resource to produce electrical energy during certain points in the future once demand is high or while the price is more viable than the storage charges, is among the auspicious ESS technologies that can stock surplus energy generated by power plants and other renewable energy resources. An electrolyzer, hydrogen tank, fuel cell system, and power conversion systems are among the essential subsystems included in this ESS [8]. Reversible fuel cells, unlike battery technologies, can transform power to hydrogen, that can be saved in storage facilities or geological structures for years without compromising its energy storing capacity [9].

2. Background and Literature Review

Ever since it was introduced in the early 1970s, hydrogen technology and the broader connotations of its development and application, the so-called hydrogen economy, have received substantial attention [5]. Hydrogen is being used as a low-emission fuel for vehicles, heating and cooling, and storing extra electricity, with the added benefit of being able to use the stored hydrogen for automobile applications, unifying the transportation and to power energy sectors. As demonstrated by pilot programmes like Fukuoka, Japan, an entire city could function on hydrogen with nearly little emissions. The notion of a Hydrogen Economy is based on this adaptability [10].

Renewable energy costs have dropped dramatically in recent years, and they are expected to fall even further in the near future. As a result, there is a genuine possibility of renewable hydrogen manufacture for both transportation and home applications [11]. Amongst renewables, solar has the ultimate potential to produce the affordable electrical power contrasted with solar thermal, wind, biomass and geothermal [12]. Solar-hydrogen is a clean alternative energy source that may replace fossil fuels and eliminates the need for oil and gaseous fuels, reducing CO_2 emissions and preventing global warming [13]. Solar energy is an abundant and reliable source of energy that can be used to produce the electricity needed for the process of water electrolysis [14]. Once rooftop solar systems produce additional electricity than residential load demand, the leftover is currently served into batteries in off-grid applications or charged into the grid in on-grid applications, with the price of electricity charged to the grid factored into the customer's utility bill [15]. Today's electrolyzers are prohibitively expensive. Nonetheless, the idea of cracking water particles to oxygen and hydrogen and then utilizing them in a fuel cell with the excess electricity supplied by rooftop PV systems is amazing [16]. Conventional batteries due to their low storage capacity and short lifespan, are not suitable for long-term energy storage [17]. Renewable energy storage in the shape of hydrogen, rather than conventional battery storage, is much more efficient and reliable [18]. Consequently, if the fuel cell prices are reduced, production of hydrogen from excess electricity and utilizing it as a battery to produce electrical power when the sun is already not shining will be cost-effective. Conversely, due to the invariable nature of solar energy, a larger capacity electricity storage system is needed to retain electrical power in order to maintain grid stability [19]. By integrating the solar system with the electrolysis process, Solar-hydrogen is a potential candidate for addressing this problem.

Hydrogen can improve the overall suppleness of low-carbon energy systems by connecting energy supply and demand in both centralized and decentralized systems. Even though the energy and environmental sustainability of hydrogen fuel in end-use applications seem encouraging, the implementation of hydrogen production techniques, transmission and distribution infrastructure, and marketing infrastructure is crucial [20].

Investigation on the applied solar electricity generating method provides a meaningful procedure in producing Solar-hydrogen to resolve the energy demands needed for an industrialized society. As a result, the goal of this article is to examine available Solar-hydrogen generation technique in order to ensure hydrogen energy to be used as an electric power generation approach.

3. Research Methodology

Selecting a location to assess, defining resources, stating input-data (monthly-average solar irradiation) for the selected location, calculating Electric Vehicle (EV) load demand and charging pin-plug consumption, modelling proposed charging station using HOMER software, and decisively choosing the most cost-effective situation based on hydrogen creation costs have all been part of the methodology used in this study.

Jamshoro, Pakistan (25°25.8′N, 68°16.9′E) was considered as the study region for developing an EV charging station concept in this study. Figure 1 depicts the location of the chosen site on a map.

Fig. 1 – Site map of chosen site

3.1 System description & Input parameters

3.1.1 Solar Irradiance data

The solar radiation data for Jamshoro was obtained from the National Aeronautics & Space Administration (NASA) database. The monthly mean solar Global Horizontal Irradiance (GHI) is represented in Figure 2 The scaled yearly average is found to be 5.53 kWh/m2/day.

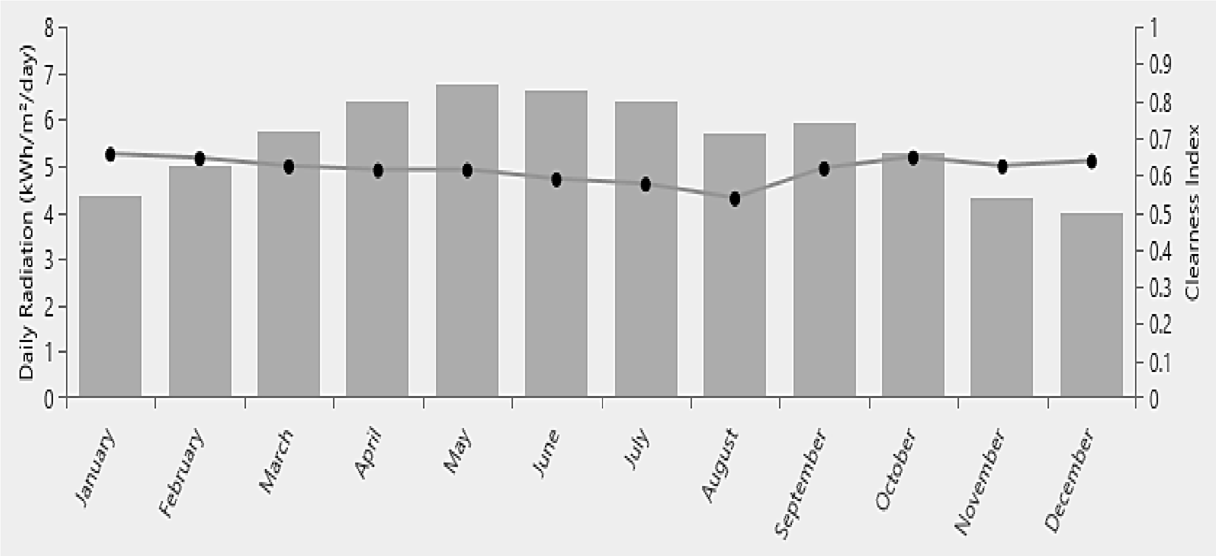

Fig. 2 - Clearness index & monthly average day-to-day solar radiation at Jamshoro

3.1.2 Charging Load Demand

Theoretically, a 22kW charging system can charge a vehicle (MG ZS EV) in about 2 hours. If a charging booth is rated 22kW then the entire load consumed by four (04) charging booths at any particular time interval will nearly be 90kW. Figure 3 shows the hourly load profile of EV charging station during the course of the year, the scaled annual average is 1750 kWh/day.

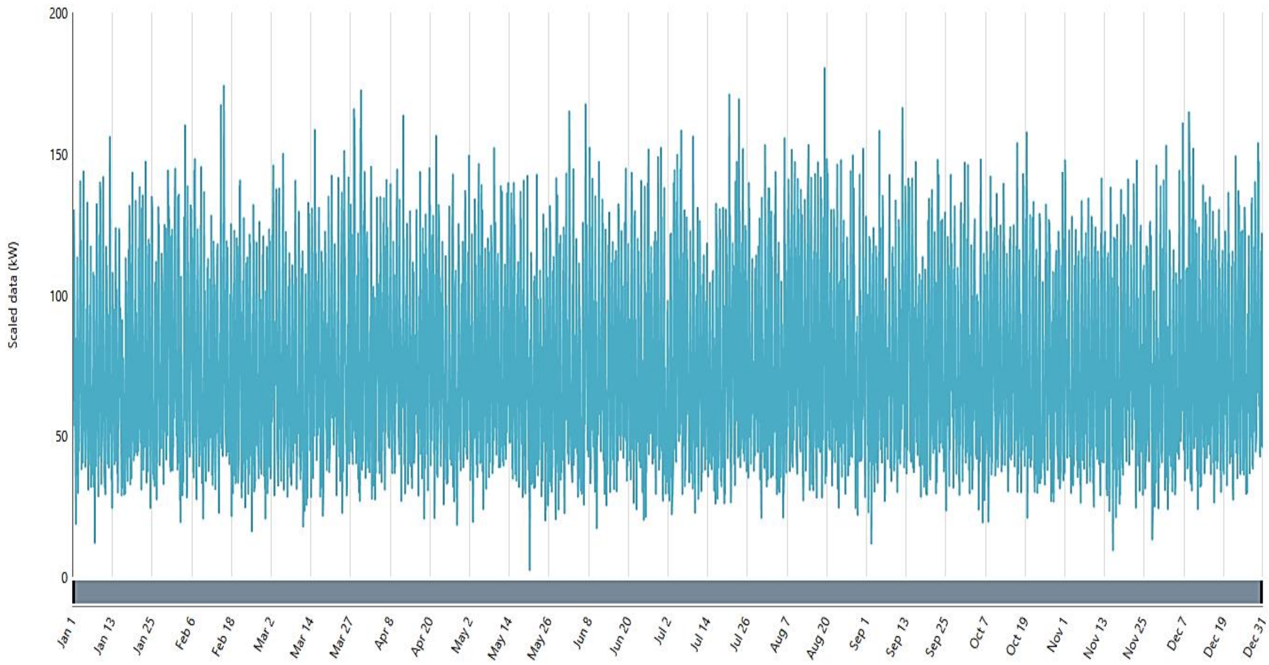

Fig. 3 - EV charging station hourly demand

3.2 Hybrid Energy System Model

The proposed hybrid PV-hydrogen energy system to provision the total generation is simulated and portrayed schematically in Figure 4 as obtained from HOMER software.

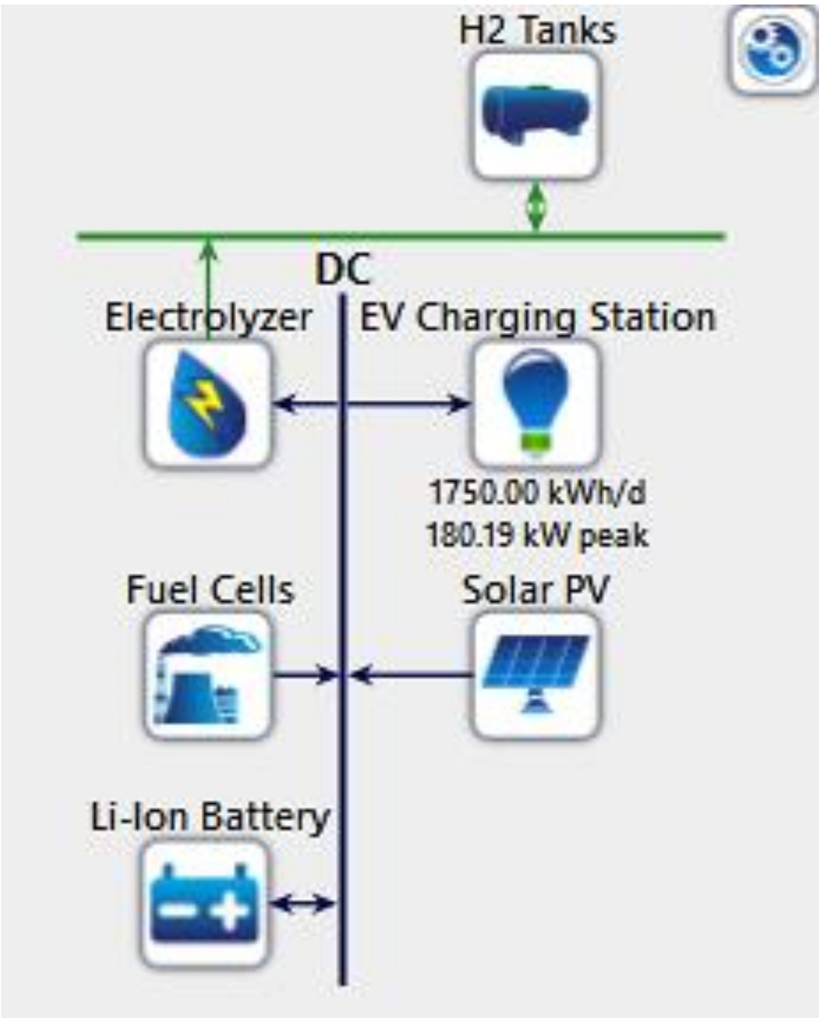

Fig. 4 – Hybrid system simulated model

The hydrogen-based energy storage system employed in this research paper comprises of an electrolyzer, a fuel cell, and a hydrogen tank. The electrolyzer in the hydrogen system produces hydrogen from surplus electricity generated by solar PVs, and it was developed to handle the extra energy. To bridge the gap among supply and demand, hydrogen is stored in a hydrogen tank before being used to generate electricity via a fuel cell. In HOMER's analysis set, the properties and cost of a proton exchange membrane (PEM) type fuel cell are taken into account. As proposed by previous studies [8, 21, 22], HOMER was used to enter the fuel expenditure rate. This translates to electrical energy efficiencies of 40–50 percent in the case of a PEM fuel cell. The energy efficiency of the electrolyzer was estimated to be 75%, with the ability to compress hydrogen gas upto 30 bars beyond atmospheric pressure, ready for storage. The capital cost of the hydrogen tank was calculated based on the system's mass production. The economic assumptions for the electrolyzer, hydrogen tank, and fuel cell were adopted from lately available articles by other scholars [8, 23-25]. Nonetheless, the cost of hydrogen storage is expected to fall in the coming years, particularly in storage applications such as those examined in this case study. The financial and lifetime details of the system's components, which were fed into HOMER in order to build the proposed model, are listed in Table 1.

Table 1 – Financial & lifetime particulars of system components.

Components	Capital Cost (US$/kW)	Replacement Cost (US$/kW)	O&M Cost (US$/year)	Efficiency (%)	Lifetime (yrs.)
Solar PV	830	830	145	13	25
Fuel Cell	600	500	0.08 $/op. hrs.	45	40,000 hrs.
Electrolyzer	2000	1200	20	75	15
Battery	390 $/kWh	390 $/kWh	0	90	10
H_2 storage Tank	435 $/kg	435 $/kg	0	-	25

4. Results and Discussion

HOMER simulates all system configurations that meet up the suggested load under provided renewable resource conditions for the chosen sites. It calculates the energy balance for each feasible system arrangement in ascending order, according to net present cost (NPC) [26, 27]. The system expenditure computation accounts for costs such as capital, operation and maintenance, replacement, and interest. HOMER reveals all of the feasible system configurations, sorted by net present cost. The comparison of two simulated systems PV/Hydrogen and PV/Hydrogen/Battery in provided in Figure 5.

Architecture						Cost			
Solar PV (kW)	Fuel Cells (kW)	Li-Ion Battery	Electrolyzer (kW)	H2 Tanks (kg)	Dispatch	COE (Rs)	NPC (Rs)	Operating cost (Rs/yr)	Initial capital (Rs)
636	100	397	250	100	LF	$0.379	$3.08M	$138,472	$1.29M
735	70.0		350	300	CC	$0.432	$3.53M	$158,608	$1.48M

Fig. 5 – Simulation results of proposed hybrid system.

The optimization consequences make clear that the wining hybrid system (PV/Hydrogen/Battery) has least possible NPC (Rs 3.08 M) with COE (Rs 0.379). Table 2 shows the details of annualized cost inspection of every component in the hybrid energy system.

Table 2 – Annualized cost details of each component.

Component	Capital ($)	Replacement ($)	O&M ($)	Salvage ($)	Total ($)
PV	40,805.37	0	92,155.73	0	132,961.10
Fuel Cell	4,641.26	1,725.69	22,664.00	212.53	28,818.43
Electrolyzer	38,677.19	9,845.83	5,000.00	1,853.08	51,669.94
Li-Ion Battery	11,976.78	10,580.74	0	1,434.57	21,122.95
H-Tank	3,364.92	0	0	0	3,364.92
System	99,465.52	22,152.26	119,819.73	3,500.18	237,937.33

Figure 6 reveals monthly electrical power produced by PV panels and Fuel cells in the best optimization results. According to the Fig. 6, it can be observed that annual average electricity production of the PV panels is around 1,266,592 kWh/yr. (89.4% of the total generated electricity) and fuel-cells can generate around 144,959 kWh/yr. (10.6% of the total generated electricity) per annum.

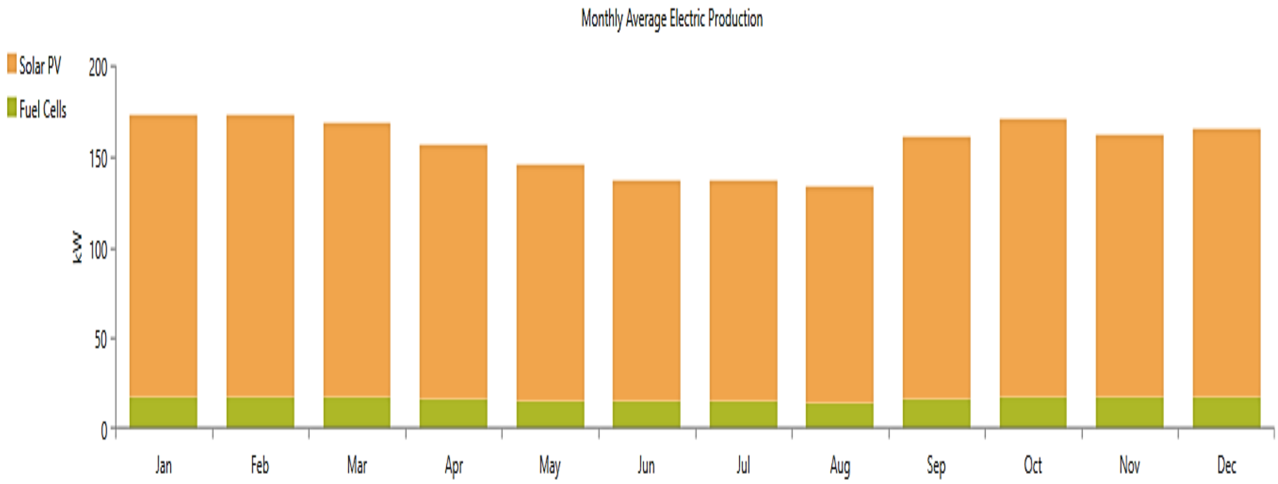

Fig. 6 – Monthly electric energy production.

Figure 7 shows daily PV output during the course of the year. It is found that the average output of the PV panels remained 140 kW, with a mean daily production of 3,361 kWh/day.

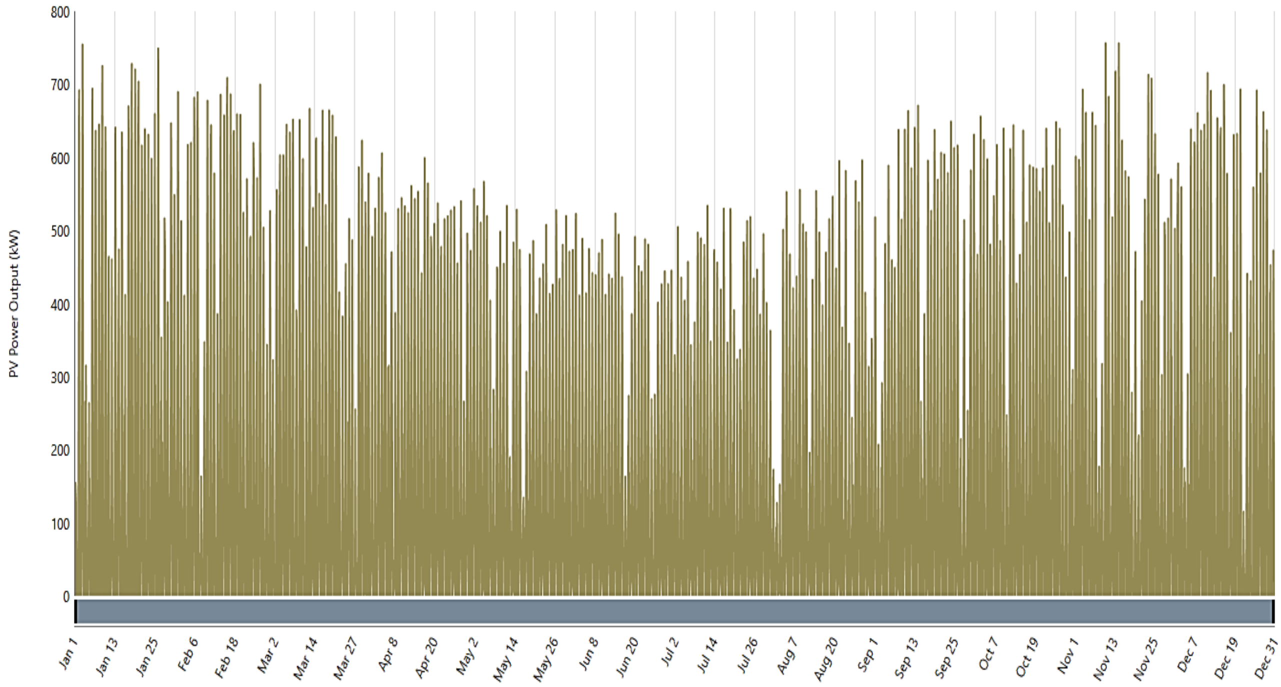

Fig. 7 – PV output during each day.

Figure 8 displays daily output of the Fuel cells throughout the year versus its fuel consumption. It is anticipated that mean electrical output of fuel cells is 51.2 kW, with an average daily electrical production of 397.14 kWh/day. The daily fuel consumption of the fuel cells was found to be 23.8 kg/day.

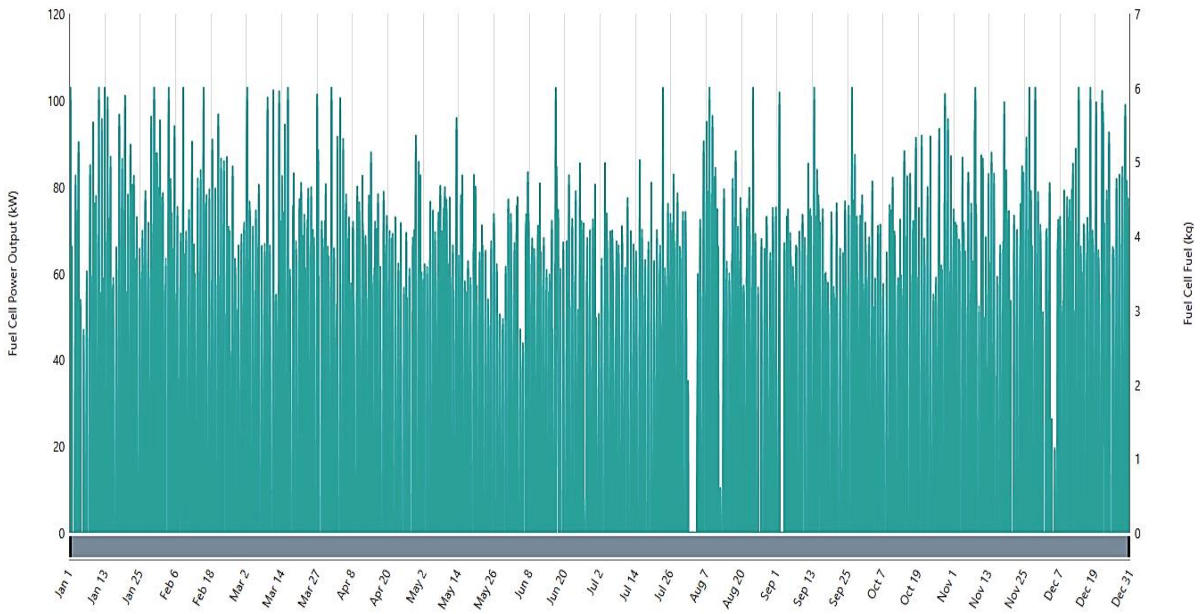

Fig. 8 – Daily power output & fuel consumption of fuel cells.

The annual hydrogen production by means of the electrolyzer is 8,690 kg/year. The daily hydrogen production against the power consumed by the electrolyzer is indicated in Figure 9. The hourly hydrogen consumption was observed to be 0.993 kg/day.

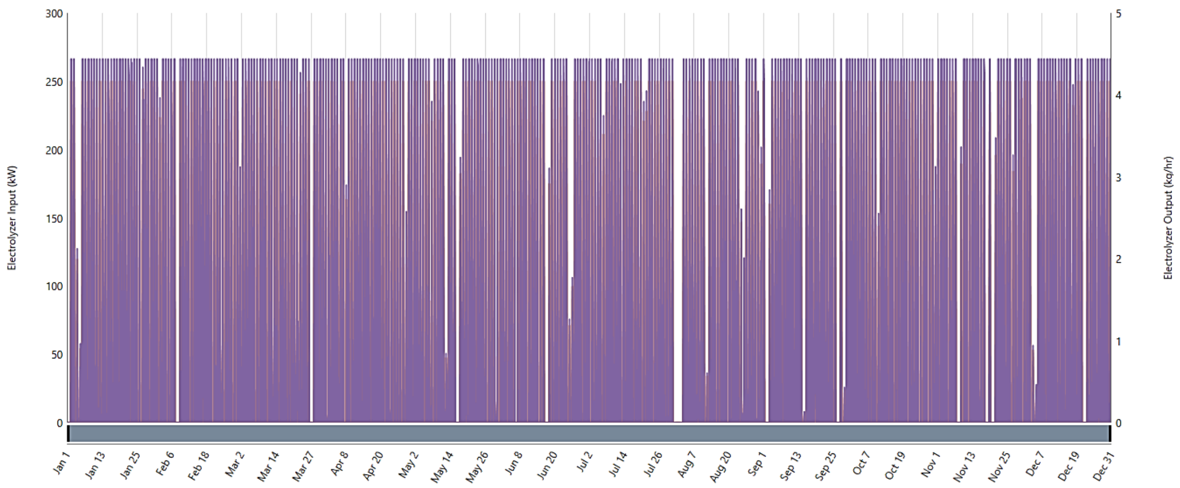

Fig. 9 – Mean hydrogen production each day

5. Conclusion

This research work explored the implication of a hydrogen-based energy system for a hybrid renewable energy idea from solar PVs in the city of Jamshoro in Sindh, Pakistan. Solar energy requires a considerable initial investment, thus shifting it to other types of energy with high-efficiency equipment is crucial. For electrolysis-based hydrogen production, PV technology offers a reliable supply of energy. The techno-economic feasibility of PV/Hydrogen/Battery energy system was reviewed using HOMER simulation software. The developed system is planned to meet the load requirement for EV charging stations, which is projected to be roughly 1750 kWh/day. The system capacity and unit cost of power were the key evaluation metrics in this research. According to the conclusions of this study PV/Hydrogen/Battery is the truly profitable method for designing a stand-alone (100 % renewable) system with the lowest net present cost. The addition of batteries lowered the size of the electrolyzer and hydrogen tanks appreciably. The system's COE declined from 0.432

Rs/kWh to 0.379 Rs/kWh as an end result. According to simulation outcomes, overall electrical energy production is a combination of energy generated by solar panels (89.4%) and fuel-cells (10.6%). The proposed stand-alone hybrid energy system's entire initial capital cost, total NPC, and operating cost were found to be 1.29M Rs, 3.08M Rs, and 138,472 Rs/yr. correspondingly.

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References

[1] J. Zhang, *Techno-economic analysis and optimization of distributed energy systems*. Mississippi State University, 2018.
[2] A. L. Dicks and D. A. Rand, *Fuel cell systems explained*. John Wiley & Sons, 2018.
[3] M. Boudellal, "Power-to-Gas," in *Power-to-Gas*: De Gruyter, 2018.
[4] J. C. Radcliffe, "The water energy nexus in Australia–The outcome of two crises," *Water-Energy Nexus,* vol. 1, no. 1, pp. 66-85, 2018.
[5] D. Parra, L. Valverde, F. J. Pino, and M. K. Patel, "A review on the role, cost and value of hydrogen energy systems for deep decarbonisation," *Renewable and Sustainable Energy Reviews,* vol. 101, pp. 279-294, 2019.
[6] P. Colbertaldo, S. B. Agustin, S. Campanari, and J. Brouwer, "Impact of hydrogen energy storage on California electric power system: Towards 100% renewable electricity," *International Journal of Hydrogen Energy,* vol. 44, no. 19, pp. 9558-9576, 2019.
[7] B. A. McCormick, "Modelling and transient simulation of solar-powered hydrogen energy storage systems," Queen's University (Canada), 2018.
[8] S. Kharel and B. Shabani, "Hydrogen as a long-term large-scale energy storage solution to support renewables," *Energies,* vol. 11, no. 10, p. 2825, 2018.
[9] O. Marchenko and S. Solomin, "The future energy: Hydrogen versus electricity," *International Journal of Hydrogen Energy,* vol. 40, no. 10, pp. 3801-3805, 2015.
[10] J. O. M. Bockris, "The hydrogen economy: Its history," *International Journal of Hydrogen Energy,* vol. 38, no. 6, pp. 2579-2588, 2013.
[11] T. Poompavai and M. Kowsalya, "Control and energy management strategies applied for solar photovoltaic and wind energy fed water pumping system: A review," *Renewable and sustainable energy reviews,* vol. 107, pp. 108-122, 2019.
[12] N. G. Dhere, "Toward GW/year of CIGS production within the next decade," *Solar Energy Materials and Solar Cells,* vol. 91, no. 15-16, pp. 1376-1382, 2007.
[13] M. Pagliaro, A. G. Konstandopoulos, R. Ciriminna, and G. Palmisano, "Solar hydrogen: fuel of the near future," *Energy & Environmental Science,* vol. 3, no. 3, pp. 279-287, 2010.
[14] P. Tao *et al.*, "Solar-driven interfacial evaporation," *Nature energy,* vol. 3, no. 12, pp. 1031-1041, 2018.
[15] H. Tebibel, A. Khellaf, S. Menia, and I. Nouicer, "Design, modelling and optimal power and hydrogen management strategy of an off grid PV system for hydrogen production using methanol electrolysis," *International journal of hydrogen energy,* vol. 42, no. 22, pp. 14950-14967, 2017.
[16] S. Véjar, J. Campos, and P. Sebastian, "Characterization of the electrical energy consumption of a building for the dimensioning of a solar - hydrogen energy system," *International journal of energy research,* vol. 34, no. 11, pp. 962-969, 2010.
[17] K. Agbossou, M. Kolhe, J. Hamelin, and T. K. Bose, "Performance of a stand-alone renewable energy system based on energy storage as hydrogen," *IEEE Transactions on energy Conversion,* vol. 19, no. 3, pp. 633-640, 2004.

[18] J. L. Bernal-Agustín and R. Dufo-Lopez, "Simulation and optimization of stand-alone hybrid renewable energy systems," *Renewable and sustainable energy reviews*, vol. 13, no. 8, pp. 2111-2118, 2009.

[19] M. Götz *et al.*, "Renewable Power-to-Gas: A technological and economic review," *Renewable energy*, vol. 85, pp. 1371-1390, 2016.

[20] S. Dunn, "Hydrogen futures: toward a sustainable energy system," *International journal of hydrogen energy*, vol. 27, no. 3, pp. 235-264, 2002.

[21] C. Lamy, "From hydrogen production by water electrolysis to its utilization in a PEM fuel cell or in a SO fuel cell: Some considerations on the energy efficiencies," *International Journal of Hydrogen Energy*, vol. 41, no. 34, pp. 15415-15425, 2016.

[22] O. Z. Sharaf and M. F. Orhan, "An overview of fuel cell technology: Fundamentals and applications," *Renewable and sustainable energy reviews*, vol. 32, pp. 810-853, 2014.

[23] H. S. Das, C. W. Tan, A. Yatim, and K. Y. Lau, "Feasibility analysis of hybrid photovoltaic/battery/fuel cell energy system for an indigenous residence in East Malaysia," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 1332-1347, 2017.

[24] V. Khare, S. Nema, and P. Baredar, "Optimization of hydrogen based hybrid renewable energy system using HOMER, BB-BC and GAMBIT," *International Journal of Hydrogen Energy*, vol. 41, no. 38, pp. 16743-16751, 2016.

[25] O. H. Mohammed, Y. Amirat, M. Benbouzid, and A. A. Elbaset, "Optimal design of a PV/fuel cell hybrid power system for the city of Brest in France," in *2014 first international conference on green energy ICGE 2014*, 2014: IEEE, pp. 119-123.

[26] A. H. Mondal and M. Denich, "Hybrid systems for decentralized power generation in Bangladesh," *Energy for sustainable development*, vol. 14, no. 1, pp. 48-55, 2010.

[27] S. K. Nandi and H. R. Ghosh, "Prospect of wind–PV-battery hybrid power system as an alternative to grid extension in Bangladesh," *Energy*, vol. 35, no. 7, pp. 3040-3047, 2010.

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