Artificial Intelligence-Enabled Techno-Economic Analysis and Optimization of Grid-Tied Solar PV-Fuel Cell Hybrid Power Systems for Enhanced Performance

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Abstract.
The incorporation of energy from renewable sources into the power grid is crucial for achieving sustainable and environmentally friendly power generation. This study proposes an artificial intelligence (AI)-enabled methodology for the analysis & optimization of "grid-tied solar photovoltaic (PV)-fuel cell hybrid power systems." The research aims to demonstrate how AI techniques can assist in decision-making, improve system performance, and achieve higher levels of energy efficiency and financial viability. The study presents the results of a project focusing on a renewable energy system that feeds into the grid and powers a university building. The hybrid power system's performance and cost were evaluated using unifiedapproaches to modeling, simulation, optimization, and control. The findings indicate that the AI-optimized "solar PV-fuel cell hybrid system connected to the grid" offers excellent performance, meeting 74% of the building's energy needs through renewable sources. The system also achieved a low levelled price for energy and minimise CO2 emissions, further enhancing its environmental sustainability. The proposed AI-enabled approach proves to be a promising solution for creating grid-connected renewable energy systems with significant benefits for energy efficiency, cost-effectiveness, and environmental impact.

Keywords:
Artificial Intelligence, Solar PV, Renewable energy, grid-tied energy system, modelling, hybrid power system, hydrogen fuel cell, simulation

1 INTRODUCTION

A combination of dynamic elements is driving a profound and nuanced revolution in the global energy landscape. These factors include the unstoppable march of population increase, the unstoppable spread of urbanization, the raging tides of industrialization, and the unstoppable spike in energy demand. The historical bedrocks of energy supply have rested on the venerable shoulders of fossil fuels, a trinity of resources comprised of coal, oil, and natural gas.

Solar, water, wind, and geo-thermal energy are examples of renewable energy sources, and have emerged as great option to fossil fuels. These sources have the potential to power civilizations without per- petuating finite resources or environmental decay. Technological leaps in energy storage, grid management, and efficiency optimization are becoming the quivers in the renewable energy bow.

As economies navigate these transitions, the synergy of policy, industry, and research becomes paramount, steering the ship towards a horizon where clean, reliable, and sustainable energy becomes the lodestar. The narrative of energy now evolves beyond merely satiating power needs, becoming an ode to balance, innovation, and securing the planet's future. The pages of history are now written in renewable ink, interwoven with the foresight to safeguard Earth's resources for generations to come. However, overreliance on these non-renewable resources has led to several challenges and concerns, including:

1. Climate Change: When fossil fuels are used, greenhouse gases like carbon dioxide (CO2) are released into the atmosphere, contributing to warmer temperatures and a shift in the weather pattern. To prevent catastrophic repercussions, the "Intergovernmental Panel on Climate Change (IPCC)" has argued that addressing climate change must be far below 2 degrees Celsius over pre-industrial levels.
2. Energy Security: As per IRENA report, many countries heavily dependent on fossil fuel imports face energy security risks due to price fluctuations and geopolitical tensions. This has prompted nations to seek more diverse and domestically available energy sources.
3. Environmental Pollution: "Fossil fuel combustion not only contributes to climate change but also causes air pollution, leading to respiratory problems and other health issues. Additionally, accidents in oil drilling, transportation, and refining have resulted in environmental disasters.
4. Depletion of Resources: Fossil fuels are finite resources, and their extraction leads to significant environmental impacts, including habitat destruction and water pollution.

To address these challenges and build a sustainable future, there is a growing global consensus on the need to transition towards sustainable power generation, characterized by:

Renewable Energy: Renewable energy sources, such as solar, wind, hydro, geothermal, and biomass, of-fer a clean and virtually inexhaustible alternative to fossil fuels. These sources do not emit greenhouse gas- es during operation, reducing carbon emissions and combating climate change.

1. Decentralization and Grid Integration: Renewable energy technologies facilitate decentralization of energy production, allowing individuals and communities to generate their own power. Integratingrenewable energy sources into the power grid enhances grid stability and resilience.
2. Energy Efficiency: Improving energy efficiency in various sectors, such as buildings, transportation, and industry, can significantly reduce energy consumption and associated emissions.
3. Technological Advancements: Advancements in energy storage, smart grids, and artificial intelligence enable more efficient management and utilization of renewable energy, addressing intermit- tency issues and optimizing power generation".

Solar photovoltaic (PV)-fuel cell hybrid power systems are gaining increasing attention as an innovative and promising solution for sustainable energy generation. The rationale behind their development lies in thesynergistic combination of two distinct renewable energy technologies, "solar PV and fuel cells," to ad- dress the limitations and enhance the benefits of each individual system.

Solar PV systems harness sunlight to directly convert it into electricity through the photovoltaic effect, offering a clean and abundant source of renewable energy. However, their intermittent nature, dependent onweather conditions and daylight availability, can pose challenges for grid integration and reliability.

On the other hand, fuel cells are electrochemical devices that continuously produce electricity by con- verting hydrogen or other fuels into electricity and heat, emitting only water and negligible pollutants. Fuel

cells provide a stable and constant power output, independent of external conditions, making them a reliable source of energy.

"By integrating solar PV and fuel cells into a hybrid system, their complementary characteristics can be harnessed to address the limitations of each technology. During peak solar generation, excess electricity can be utilized to produce hydrogen through electrolysis, storing the energy for later use in the fuel cells. This capability allows the hybrid system to balance intermittent solar power with the constant output from fuel cells, ensuring a consistent and reliable energy supply".

Numerous studies have highlighted the potential advantages of "solar PV-fuel cell hybrid power systems." A study by (Zhang et al. 2020) demonstrated that such hybrid systems can significantly improve energy efficiency and reduce carbon emissions compared to standalone PV or fuel cell systems. Additionally, the ability to store excess solar energy as hydrogen enables the hybrid system to act as an energy storage solution, enhancing grid stability and supporting renewable energy integration.

Furthermore, solar PV-fuel cell hybrid power systems offer scalability and flexibility, making them suitable for various applications, from small-scale residential installations to larger commercial and industrial setups. The technological synergy achieved through this integration can lead to cost savings over time, reducing reliance on grid electricity during peak demand periods and enhancing overall energy resilience (Ghenai et al.,2013; Alkhateeb et al.,2016).

Hence, "the combination of solar PV and fuel cells in hybrid power systems offers a promising approach to address the challenges of intermittent renewable energy sources while leveraging the benefits of both technologies. As the world seeks to transition to a sustainable energy future, these hybrid systems hold the potential to play a vital role in achieving reliable, efficient, and environmentally friendly power genera- tion".

Integrating artificial intelligence (AI) into the optimization process of "solar PV-fuel cell hybrid power systems" presents both challenges and opportunities. The incorporation of AI can significantly enhance the system's performance, but it also requires careful consideration of potential drawbacks (Heydari & Askarzaedh, 2016). Below are some of the key challenges and opportunities associated with AI integration:

1.1 Challenges:

- Data Quality and Availability: AI systems rely largely on excellent in quality and pertinent data to make precise inferences. Obtaining comprehensive and real-time data for the hybrid system's components, weather conditions, electricity demand, and other relevant parameters can be challenging and may require advanced monitoring and data collection systems.
- Model Complexity: Hybrid power systems are inherently complex, involving multiple interacting components and unpredictable external factors. Developing accurate AI models that can handle such complexity and provide meaningful optimization insights can be difficult.
- Algorithm Selection: Choosing the most appropriate AI algorithms for the optimization task is crucial. Various algorithms have their pros & cons, and selecting the right one requires an understanding of their capabilities and limitations.
- Training and Validation: Training AI models requires large datasets, and validation is necessary to ensure the models' accuracy and generalization. Overfitting or underfitting AI models to the training data can lead to suboptimal performance during real-world operation (Sen & Bhattacharya, 2014; Lan et al., 2015).

Opportunities:

- Enhanced System Performance: AI can continuously analyze real-time data, weather forecasts, and electricity demand patterns to optimize the operation of the hybrid power system. This leads to improved energy efficiency, better load balancing, and overall enhanced system performance.
- Real-Time Decision Making: AI enables real-time decision-making capabilities, allowing the system to adapt quickly to changing conditions, such as sudden variations in solar irradiance or electricity demand. This dynamic response can improve grid stability and reliability (Merabet et al., 2017).
- Predictive Maintenance: AI can predict equipment failures or performance degradation based on data analysis, enabling proactive maintenance and minimizing downtime, which is crucial for ensuring system reliability.
- Advanced Control Strategies: AI-based control strategies can optimize the coordination between solar PV, fuel cells, and energy storage systems, ensuring the efficient utilization of all available resources.
- Scalability: AI models can be tailored to suit different scales of "solar PV-fuel cell hybrid power systems," from small-scale domestic installations to large industrial setups, making the technology applicable in various contexts.
- Continuous Learning: AI models can be designed to learn from system behavior over time, leading to improved optimization and decision-making capabilities as the system operates and accumu- lates more data.
- Energy Market Integration: "AI can facilitate participation in energy markets by predicting electricity prices, allowing the hybrid system to buy or sell electricity strategically, potentially leading to cost savings or revenue generation (Ghenai & Janajreh, 2016; Lambert et al., 2006; Yilmaz et al., 2015).

2 LITERATURE REVIEW

PV-fuel cell hybrid power systems and their performance. Here are some key findings from previous studies:

1. Techno-Economic Analysis and Optimization of Solar PV-Fuel Cell Hybrid Systems:

A study by **Pang et al. (2019)** conducted a techno-economic analysis of a grid-connected solar PV-fuel cell hybrid system. They found that the hybrid system reduced the overall cost of electricity generation compared to standalone PV or fuel cell systems. The optimization of the system's operation based on weather forecasts and electricity demand patterns resulted in improved energy efficiency and financial viability.

(Ghenai et al., 2020) created a hybrid solar PV/fuel cell power plant to handle the electric load of a desert-area residential subdivision. The system was developed with a renewable component of 40.2% and a levelized cost of energy of 145 $/MWh in mind. The method was proven to be both economically and environmentally sustainable.

The system met the residential community's AC primary load with low unmet load. The system generated 52% of its power from solar PV and 48% from gasoline. The researcher came to the conclusion that the

suggested hybrid renewable power system is a realistic choice for satisfying the electric load of desert towns. The system is both economically and environmentally feasible, with a high renewable component.

2. Energy Management Strategy for Hybrid Systems:

Chen et al. (2017) proposed an energy management strategy for a grid-connected solar PV-fuel cell hybrid system. The study focused on achieving load leveling and energy self-sufficiency through coordinated control of the PV system, fuel cell, and energy storage. The proposed strategy showed promising results in minimizing grid dependence and ensuring a continuous power supply.

(Hu et al., 2021) suggested fuzzy control technique for HESS in ships may successfully split the charge and discharge functions of the HESS to fulfil the ship's power requirement. The method also ensures that the HESS is always in good working order, which is critical for the ship's safety and reliability.

The experimental findings demonstrate that the proposed technique is successful and can increase the HESS's performance.

The findings of this work have implications for the energy distribution and capacity configuration of HESS. The findings indicate that fuzzy control could be a promising strategy for managing HESS in ships, leading to the development of more efficient and dependable HESS systems.

(Wang et al., 2023) offer an energy management technique based on reinforcement learning that can efficiently distribute the power supply's charging and discharging circumstances, preserve the state of charge (SOC) of the battery, and fulfil the demand for power of working conditions while consuming less energy. They use simulations to test the proposed technique, and the findings demonstrate that it can considerably improve the efficacy and lifespan of the hybrid energy storage system.

3. Dynamic Power Dispatch for Hybrid Systems:

(Qu et al., 2017) propose a unique multiple-purpose dynamic economic emission dispatch (DEED) model is proposed, taking into account EVs and wind power uncertainty. The DEED model reduces total fuel costs and polluting emissions while guaranteeing the system satisfies energy & user demand. To opti- mise system efficiency, the charging as well as discharging behaviour of the EVs is dynamically regulated. To ensure that the DEED model's constraints are met, a two-step constraint processing technique is pro- vided. The MOEA/D algorithm is being enhanced in order to find superior alternatives to the DEED model.The 10-generator system validates the suggested model and approach, and its outcomes indicate they are viable and logical.

In a study by **Lai et al. (2019)**, an AI-based dynamic power dispatch algorithm was developed for a solar PV-fuel cell hybrid power system. The algorithm optimized the power output from the PV system and fuel cell to meet the varying electricity demand throughout the day. The dynamic dispatch approach improved the system's response to changing conditions and increased overall energy utilization".

4. Hydrogen Storage and Management:

Research by **Patel et al. (2018)** focused on the hydrogen storage and management aspects of solar PV-fuel cell hybrid systems. The study explored different hydrogen production methods, storage technologies, and the role of hydrogen in enhancing the system's energy storage capacity. The integration of hydrogen storage in the hybrid system improved energy resilience and facilitated better utilization of excess PV power.

(Iqbal & Mohammad, 2022) present a power management method for a DC microgrid made up of solar PV, batteries, fuel cell, and kept hydrogen. They employ HOMER software to assess the viability of the suggested system design for a remote area in North India. The results show that the structure is financially viable, with an overall NPC of $83,103. Time-domain simulations are also run to ensure the system's tech-

nological feasibility. The results reveal that the suggested approach can electrify ventilator important loads effectively even under fluctuating solar irradiation circumstances.

4. Environmental Impact Assessment:

(Akyuz et al., 2010) discovered that a hybrid electrical system can greatly cut greenhouse gas emissions & electricity costs in chicken production. The researchers also discovered that DSM can lower annual electricity usage by 15% while also improving the hybrid power system's techno-economic viability.

(Anayochukwu, 2013) showed that when compared to a DG power system, a hybrid power system with 69% renewable energy penetration can lower the amount of different air pollutants by up to 69%. The HOMER programme was utilized to create a theoretical model that compares the environmental impact of various power systems for GSM base station locations.

A study by **Zhang et al. (2018)** conducted a life cycle assessment of a "solar PV-fuel cell hybrid sys- tem" to evaluate its environmental impact. The analysis considered the environmental burdens associated with manufacturing, installation, and operation of the hybrid system. The outcome indicated a decrease in carbon dioxide emissions compared to conventional energy generation methods.

(Alharthi et al., 2018) analysed and compared the efficacy of six alternative "photovoltaic (PV) monitoring systems" with "diesel-battery" combination systems in the "(KSA) Kingdom of Saudi Arabia's" desert climate. The study found out that because of its low NPC, LCOE, and CO2 emissions, the VCA system is the most cost-friendly tracking method for PV installations in KSA.

3 Methodology

3.1 Introducing the AI-Powered Approach:

Our novel technique incorporates the utilization of AI to enhance the performance & cost viability of grid-connected "solar photovoltaic (PV)-fuel cell hybrid power systems." We intend to do detailed techno-economic analysis and streamline system operation by incorporating AI technology. Our AI-powered platform continuously evaluates real-time data, weather forecasts, electricity usage trends, and system characteristics to make dynamic decisions that result in improved system performance.

3.2 Data Collection and Preparation for System Modelling:

Accurate data collection is critical for developing a reliable system model. Solar radiation data, ambient temperature, fuel cell efficiency data, power usage, and other relevant operational information are all collected. Weather stations, sensor arrays, smart metres, and historical records can all provide data.

We use preprocessing procedures to assure data quality and consistency. This includes cleaning the data, filling in any missing information, and standardising the data so that it can be used to train AI models and optimise performance.

3.3 AI Algorithm Selection and Implementation for Optimisation:

The optimisation method employs tailored AI algorithms based on the system's aims and complexity. Among the probable AI algorithms for optimisation are:

a. GA (Genetic Algorithms): Natural selection inspires this population-based optimisation strategy. It excels at tackling complex and nonlinear issues, making it ideal for optimising the functioning of hybrid solar PV-fuel cell systems.

b. Artificial Neural Networks (ANN): These networks are used to represent complex interactions between system variables. It forecasts solar radiation and energy consumption trends and improves the control techniques of the system.

c. Reinforcement Learning (RL): RL is used to control and distribute electricity dynamically. This enables the system to learn from its interactions with its surroundings, gradually enhancing its decision-making capabilities.

d. Particle Swarm Optimisation (PSO): PSO is a stochastic optimisation technique that can be used to solve hybrid system difficulties such as sizing and distribution of PV and fuel cell components.

These chosen AI algorithms are then put into action using relevant programming languages and frameworks (for example, Python with TensorFlow or PyTorch libraries). Using historical data, the AI models are trained and tested, and their performance is measured against established parameters such as energy consumption, affordability, and carbon reduction.

Because AI-based optimisation is iterative, the system can adapt to shifting circumstances and constantly improve its performance. This artificial intelligence-enhanced methodology ushers in a more comprehensive and dynamic approach to the techno-economic analyzation & optimisation of "grid-connected solar PV-fuel cell hybrid power systems," resulting in greater system performance and economic feasibility.

3.4 System Model Development: "Hybrid Solar PV-Fuel Cell Power System"

The "solar photovoltaic (PV) system & the fuel cell syste form the backbone of the "hybrid power system." These components work together to generate power & meet the system's needs.

1. "Solar Photovoltaic (PV) System": It is a made up of solar panels, inverters, and, in some cases, a tracking system. Solar panels use the photovoltaic effect to turn sunlight into power. Inverters converting electricity from generated (DC) direct current to (AC) alternate current allowing integration with the grid. If a tracking system is present, it optimises the orientation & angle of the solar panels based on the location of the sun to maximise energy capture.

2. "Fuel Cell System": The fuel cell system includes critical components including the fuel cell stack, reformer (if necessary), hydrogen storage tanks, and other plant components. Hydrogen and oxygen undertake electrochemical reactions within the fuel cell stack that generate water and power. The reformer transforms hydrocarbon fuels into hydrogen for fuel cell operation if necessary. When solar generation is insufficient, hydrogen is kept in tanks to offer a continuous and stable power output.

3. Component Interaction: The interaction of the "solar PV & fuel cell systems" is critical for system optimisation. Surplus electricity generated during peak solar generation can be used to electrolyze water and make hydrogen. When solar generation is minimal, this hydrogen is kept and utilized by the fuel cell system to generate energy. The control method of the hybrid system decides the power production from every element based on real-time solar radiation, demand for electricity, and stored hydrogen levels, assuring a consistent and efficient energy supply.

4 Mathematical Modeling:

4.1 Solar PV System Modeling:

"The mathematical model for the solar PV system typically includes the performance characteristics of the solar panels, considering factors such as solar irradiance, ambient temperature, and module temperature.This model uses the single-diode or double-diode equations to estimate the PV panel's current-voltage (I-V)and power-voltage (P-V) characteristics. The performance model can also account for degradation and aging effects over time.

4.2 Fuel Cell System Modeling:

The mathematical model for the fuel cell system involves various sub-models for the fuel cell stack, reformer (if applicable), and hydrogen storage. The fuel cell stack model considers factors such as hydrogen and oxygen flow rates, operating temperature, and cell voltage characteristics. The reformer model (if used) estimates the efficiency of hydrogen production from the reforming process. The hydrogen storage model predicts hydrogen storage capacity and performance".

4.3 Hybrid System Interaction Model:

To optimize the hybrid system's operation, a control algorithm is designed based on the interactions between the "solar PV" & "fuel cell systems." The control algorithm determines the optimal power output from each component to meet electricity demand while minimizing operational costs or maximizing energy efficiency. This may involve state-of-charge (SoC) control for hydrogen storage, load leveling, and dynamic dispatch of power between the PV and fuel cell components.

5 Software Tools and Platforms Used for Simulation:

Various software tools and platforms can be used for simulating the "solar PV-fuel cell hybrid power system". Some commonly used tools include:

1. MATLAB/Simulink: MATLAB and Simulink provide powerful simulation capabilities and can be used for both modeling the individual components and optimizing the hybrid system's operation.
2. HOMER (Hybrid Optimization Model for Electric Renewables): Hybrid power systems, such as "solar PV-fuel cell hybrids," may benefit from the techno-economic analysis and optimization provided by HOMER.

6 Results and discussions

As can be seen in Fig. 1, "the components of the grid-connected hybrid power system consist of solar PV panels, a fuel cell, an electrolyzer, a hydrogen storage tank, an inverter (DC/AC power conversion), andthe utility grid. The AC load is calculated from the total energy use of the building (heating, cooling, light- ing, and other appliances). Additional background on the equations used to determine solar PV, fuel cell, and electrolyzer output and input powers" is provided by the work of Ghenai et al.[15-16]

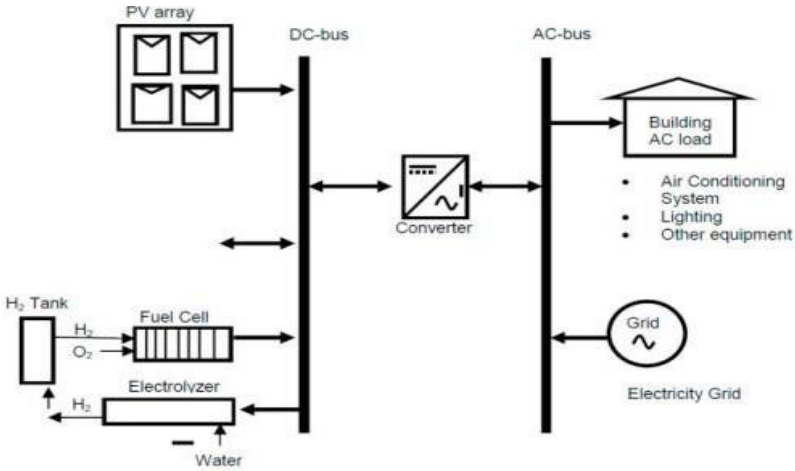

Fig.1. "Grid-connected solar photovoltaic/fuel-cell hybrid power generation"

The "hybrid energy system" was planned to provide the commercial building's daily energy needs of 6,540 kWh. In order to determine how much power goes into and out of each part, "thousands of hours were spent simulating and optimising. Using an optimization search space, the optimum solutions for the hybrid power system's LCOE minimization were found. The simulation and optimization method is based on the microgrid power system model that was selected (Pang et al., 2019).

The design configuration (Solar PV, fuel cell, and utility grid), search space (maximum power capacity off each component), and daily power consumption for the building are input into a simulation, and the results are analysed for technical feasibility and life cycle cost. The optimization approach models many configurations (single component like solar PV alone or combination of two or more components like solar PV/fuel cell) to identify the best system design that satisfies the technical constraints and has the lowest life cycle cost.

According to the results of the simulation and optimization, Systems 1, 2, 3, and 4 have the cheapest energy costs. The first (System 1) only makes use of the grid as a reference point; the second (GT120) uses the grid in conjunction with solar photovoltaics (PV) with a 120 kW capacity and a fuel cell with a 100 kW capacity; the third (GT250) uses the grid in conjunction with PV with a 250 kW capacity and a 100 kW fuel cell; and the fourth (GT500) uses the grid in conjunction with PV with a 500 kW capacity. Table 2 summarises the solar photovoltaic (PV), fuel cell, and inverter capacities of grid-connected hybrid power systems. Figure 2 depicts the main load consumption, grid utility purchases, surplus power sales, and solar PV/fuel cell power system energy production for both off-grid and grid-tied solar PV/fuel cell power systems.

Power generation in all three grid-connected solar PV/fuel cell systems is shown by simulation results and the technical constraint (lowest cost of energy) in the form of cycle charging control strategies (the generator or fuel cell will run at maximum capacity to meet the AC primary load and the excess power is used for the power input of the electrolyzer or to charge the battery if used). All of the grid power used by the primary AC load in the reference system (system 1) is used up. Total electrical production for the GT120 system is 2,508,541 kWh/yr, with 1,369,294 kWh/yr coming from the grid (55 percent), 875,208 kWh/yr coming from the fuel cells (35 percent), and 263,039 kWh/yr coming from the solar PV system (10 percent).

The grid-tied power system (system 2) provides all of the electricity needed to meet the building's annual AC main consumption of 2,387,100 kWh, with a surplus of 74,490 kWh being sold back to the utility company. The GT250 power plant's System 3 produces 2,526,309 kWh/yr total, with 44% coming from purchasing grid energy (1,105,552 kWh/yr), 35% from the fuel cell (87,278 kWh/yr), and 54% from the solar PV system (22 percent). The grid-tied power system (system 3) provides all of the electricity needed to meet the building's annual AC main consumption of 2,387,100 kWh, with any excess electricity being sold back to the grid at a rate of 3 percent, or 81,985 kWh. System 4 of the GT500 power system is a grid- connected hybrid energy system that produces 2,596,380 kWh annually. There are three main sources for this sum: the grid (677,170 kWh/year, or 26 percent), the fuel cell (823,213 kWh/year, or 32 percent), and the solar PV system (1,095,996 kWh/year, or 17 percent) (42 percent).

As can be seen in Fig. 2, the building's yearly AC main demand of 2,387,100 kWh is completely ful- filled by the electricity generated by the grid-tied power system (system 4), with 132,090 kWh, or 5% of the total production, being sold back to the grid. The average power output of the PV array for grid- connected solar PV/fuel cell hybrid power systems was reported to be anywhere from 30 kW for the GT120(120 kW solar PV capacity) to 63 kW for the GT250 (250 kW sun PV capacity) and 125 kW for the GT500(500 kW solar PV capacity). Three grid-connected solar PV/fuel cell power plants achieve 25% capacity factor with yearly solar PV operation of 4345 hours. The maximum fuel cell power for any of the three designs is 100 kW. The average power output of the fuel cell is 100 kW, with an average electrical effi- ciency of 68%. The fuel cell requires 0.04 kg/kWh of fuel. Inverter power capacities of 193 kW, 295 kW, and 477 kW are used in grid-connected solar PV/fuel cell power systems ranging in size from GT120 to GT500 (See Table 2). The typical inverter output for the GT120, GT250, and GT500 power systems is 125 kW, 156 kW, and 210 kW, respectively. The capacity factors of the inverters used in the GT120, GT250, and GT500 power systems were 66%, 53%, and 44%, respectively. Inverter power losses, which occur when DC power is converted to AC power, average about 4% across all three power system architectures.

Daily performance of the GT500 grid-tied solar PV/fuel cell power system is shown in Figure 3 over the course of four days (July 24-27). The PV system provides the bulk of the needed energy during the day, when solar irradiation is at its peak, while the remaining is drawn from the grid. During the evening hours, the fuel cell is the primary source of electricity, with the grid filling in the gaps. The GT500 grid-connected solar PV/fuel cell power system provides all of the required AC for the buildings", with five per cent of the power generated by fuel & solar cell technology are offered for sale back to the grid. earn revenue and reduce energy costs.

Table 1. Components and technical details of hybrid electrical systems.

System Component	**Description**
Solar PV	Type: "Canadian solar CS6U-330"; module: polycrystalline; nominal maximum power = 330 W; operating temperature 45o C; efficiency = 16.97%; and derating factor fPV = 80%. O&M = $3/year, life time = 25 years. Cost per 1 kW: capital = $1200; replacement = $1200;
Hydrogen Tank	Cost per 1 kg: capital = $0.5; life time = 25years, O&M = $10/year.
Fuel Cell	Type: "PEM Fuel cell (DC power)"; fuel: hydrogen; and electrical efficiency hFC = 70%. O&M = $0.01/hour, life time (hours) = 50,000. Cost per 1 kW: capital = $400; replacement = $400;

Inverter/Rectifier	O&M = $10/year, life time = 25years. Cost per 1 kW: capital = $40; replacement = $40;
Converter:	Type: "Leonics S219CPH"; voltage = 48 VDC with an efficiency = 96%
Electrolyzer	Type: "generic electrolyzer (DC power)", Efficiency hEZ = 90%. O&M = $8/year, life time = 15years. Cost per 1 kW: capital = $100; replacement = $100.

Table 2. "Solar photovoltaic (PV) and fuel cell (FC) power systems" synced with the grid.

System	Grid	Solar PV Capacity (kW)	Fuel Cell Capacity (kW)	Inverter Capacity (kW)
Baseline - Grid only	yes	0	0	0
GTPV120	yes	120	100	193
GTPV250	yes	250	100	295
GTPV500	yes	500	100	477

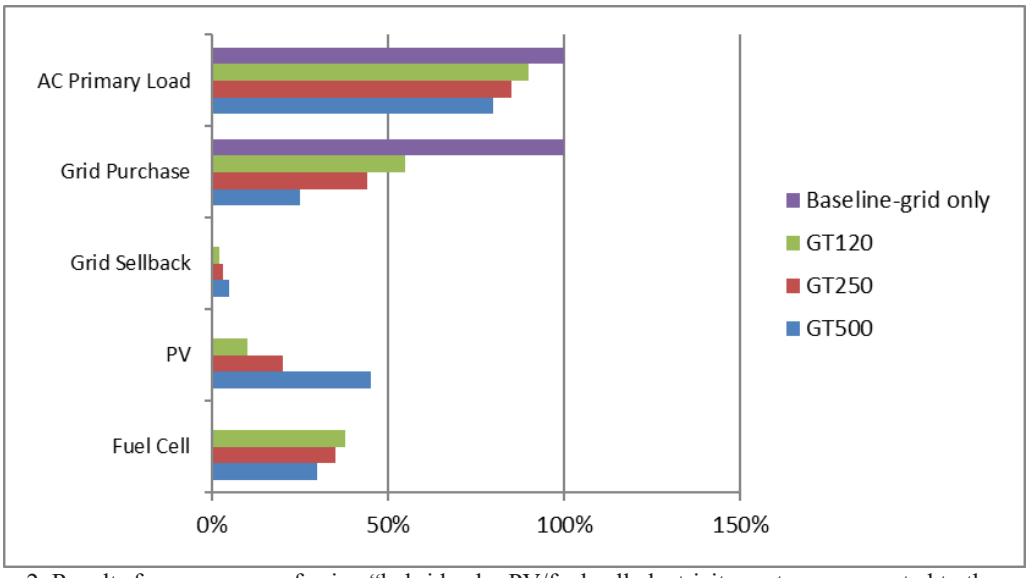

Fig. 2. Results from one year of using "hybrid solar PV/fuel cell electricity systems connected to the grid"

Table 3 compares the three "grid-connected solar PV/fuel cell power systems" based on their renewable share, energy cost, and decrease in CO2 emissions. "When coupled with the grid, the renewable fractions produced by the GT125 solar PV/fuel cell, the GT250 solar PV/fuel cell, and the GT500 solar PV/fuel cell are 8.8 percent, 19.9 percent, and 40.4 percent, respectively. The GT500 power system (system 4) with coupled solar power of 500 kW and fuel cell power of 100 kW with the grid offers the best solution in terms of renewable component (40.4%), energy cost,renewable component (40.4%), and CO_2 emissions (133 kg CO2/MWh). Figure 3, 4, and 5 shows graph of comparison for the three "grid-connected solar PV/fuel cell power systems" based on their clean and green share, energy cost, and decrease in CO_2 emis- sions.

The whole energy need of the structure will be covered, and the extra 5% of production will sold to the grid. A "grid-tied solar PV/Fuel Cell power system" ensures constant access to electricity while also having a much lower life-cost of energy in contrast to an off-grid system. The annualised costs of the "hybrid solar PV/Fuel Cell power system" are broken out in Table 4. Initial investment, O&M, fuel, and replacement costs for "grid-connected solar PV and fuel cell power systems."

Table 3. Grid-connected solar PV and fuel cell power systems: a summary of renewable share, energy cost throughout lifetime, and carbon dioxide emissions

System	Cost of energy ($/MWh)	CO2 emissions (kg/MWh)	Renewable fraction (%)
Baseline – grid only	120	632	0
GTPV120	93	326	8.8
GTPV250	86	256	19.9
GTPV500	71	133	40.4

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Fig. 3. Comparison Graph of the renewable fraction for the "Grid-connected solar PV and fuel cell power systems"

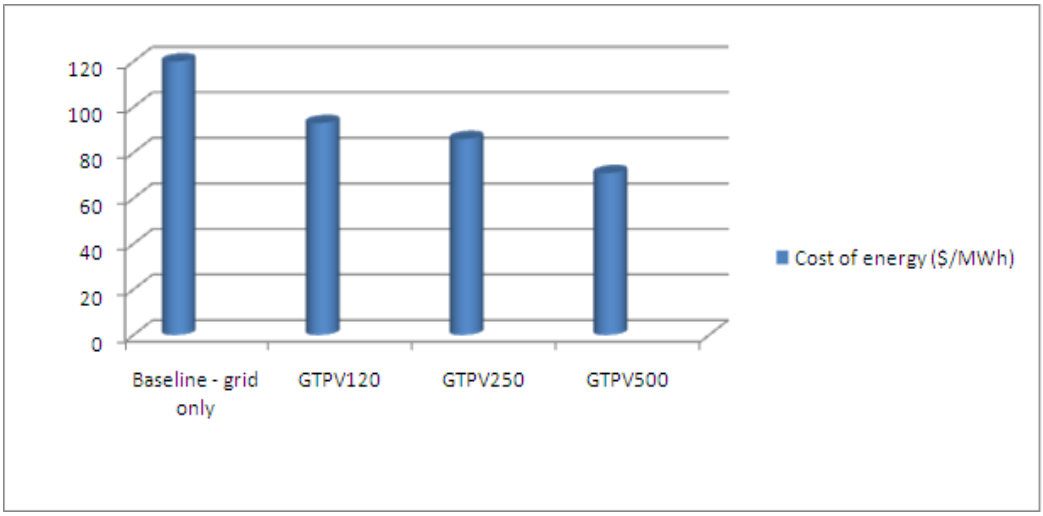

Fig. 4. Comparison Graph of the cost of energy for the "Grid-connected solar PV and fuel cell power systems" throughout the lifetime

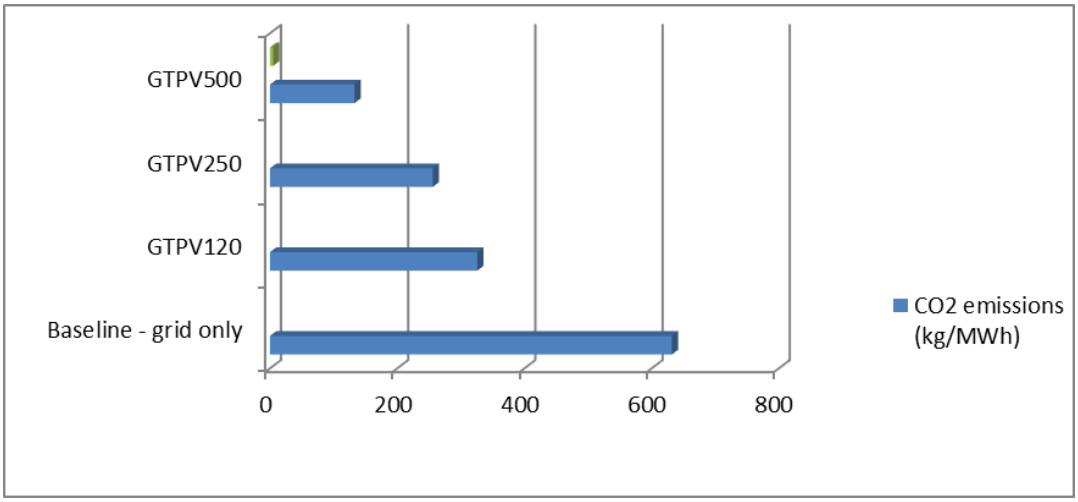

Fig. 5. Graph of the CO_2 Emission comparison for the "Grid-connected solar PV and fuel cell power systems"

Table 4. Grid-connected solar photovoltaic and fuel cell power systems: a summary of their annualised costs

System	"O&M ($)"	"Fuel ($)"	"Replace-ment" ($)	"Capital ($)"	"Total ($)"
Baseline - grid only	286,452	0	0	0	
GTPV120	171,029	38,509	5,861	14,868	229,804
GTPV250	140,335	38,401	5,855	27,256	211,37
GTPV500	88,017	36,221	5,633	51,020	180,250

7 Summary & Conclusions

In this article, a "grid-tied solar PV/fuel cell hybrid power system" for a The University's Administration Building, a commercial structure, is displayed., along with its design and analysis. The energy audit data was used to establish the key loads for the building's air conditioning system. This research examined Shar-jah's renewable resources, current technology for renewable energy, technology pricing, system expense, and resource constraints. "Using a unified suite of modelling, simulation, optimization, and control ap- proaches, the proposed grid-connected hybrid solar PV/fuel cell power system's efficiency and cost were assessed. Researchers looked examined how the solar PV power capacity of a system relates to its perfor- mance (renewable percentage, cost of energy, and greenhouse gas emissions). According to the results, the grid-connected solar PV/Fuel Cell grid power system generates more than enough energy to meet the build-ing's annual electricity needs and even has enough left over to be sold. The levelized cost of electricity generated by the grid-connected solar PV/fuel cell hybrid power system is just $71 per megawatt hour (MWh), while carbon dioxide (CO2) emissions are only 133 kg/MWh (MWh). Integration of renewable power systems with the utility grid is one of the best techniques and effective approaches to increase the penetration of renewable energy in the energy mix at an acceptable cost of energy, reduce reliance on fossil fuels, and mitigate environmental impacts (greenhouse gas emissions reductions").

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