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Artificial intelligence-driven short-term energy forecasting of an off-grid solar PV/hydrogen fuel cell-powered AI-data center: AI-energy Nexus

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Abstract. Powering AI data centers with renewable hydrogen is a promising energy option. This strategy has the potential to satisfy the high energy requirements of AI-data centers while simultaneously reducing the amount of carbon emissions produced. In order to keep up with the demand for green hydrogen, well-planned infrastructure, investments in renewable energy, electrolyzes, fuel cells, and hydrogen storage are essential. In order to maximize green hydrogen production, decrease operational costs, increase energy efficiency, precise solar power forecasting and green hydrogen production are crucial. The main objective of this study is to assess the performance of green hydrogen power systems to meet the load of AI-data centers and to develop AI-based short term energy forecasting models. This study models and simulates the proposed clean power system to evaluate the performance of AI-data centers. This study will examine the technological, financial, and environmental elements of the proposed green hydrogen-based power system for the AI-data center's massive power requirement and the proposed energy forecasting models. The challenges associated with power and heat management of AI data center and emerging and sustainable solutions for incorporating clean energy technologies and energy efficiency will be discussed in more detail.

Introduction

The AI data centers support high performance computing (HPC), parallel computing, and Artificial intelligence (AI) workloads. The computational intensity of the AI data centers is extremely high. Graphical processing units (GPUs) are essential to accelerate AI workloads to speed up the inference and training process of AI systems. The specialized hardware such as accelerators GPUs and could tensor processing units (TPUs) consume more power compared to regular data center [1]. The AI Workloads require substantial amounts of data. To accommodate shifting workloads, storage must scale quickly. Networking system with high-speed connections is also needed to process the huge amount of data. The AI increases IT equipment power consumption due to growing storage, networking, and hardware needs of the AI data center. The AI Data centers have high rack density and high-power density (kWh/m2). In addition, advanced and innovative cooling systems of the AI data centers are needed to reduce the temperature and regulate the heat release for the servers via liquid or immersion cooling. The AI data centers have high cooling requirements. Inefficient power and cooling systems characterize AI data centers with 24/7 operations. For environmental impacts, AI data centers massive energy consumption raises greenhouse gas emissions and air pollution, and high-water demand for the cooling system.

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Mitigation strategies as shown in Fig.1 are needed to reduce the environmental impacts of high-power demand of AI data centers. Tech companies are investing in renewable energy sources to power their data centers [2]. Modern innovations such as immersion cooling and AI-powered cooling system optimization can significantly cut down on water and energy use [3]. More efficient, durable hardware and AI optimization methods [4] and strategies are needed to manage and reduce the power consumption and carbon footprint of AI data center.

The principal objective of this project is to evaluate green hydrogen power solutions for AI-data centers. Green hydrogen is a viable and sustainable energy source for AI data centers. AI-data centers need large amount of electricity, yet they should reduce carbon emissions. Meeting hydrogen demand requires well-planned infrastructure and investment in renewables, electrolyzers, fuel cells, and hydrogen storage.

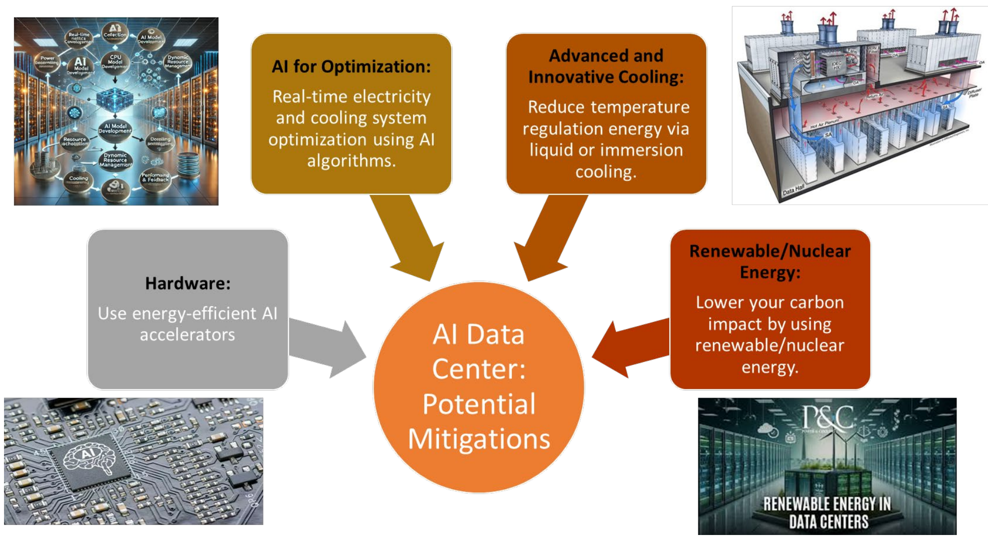

Figure 1. AI Data Center: Potential Mitigation Strategies

Modeling and Simulation Analysis

AI Data Center Electrical Load: The AI data center has 50 servers with 2.5 kW each. The center uses 70% of total power during peak hours for 12 hours and 20% of the total power during idle hours (~12 hours). During peak hours, the servers consume: 50 x 2.5 x 0.70 x 12 = 1,050 kWh/day. During the idle time, the AI-servers consume: 50 x 2.5 x 0.2 x 12 = 300 kWh/day. The daily total AI-servers electrical energy consumption (Peak Hours + Idle) = 1350 kWh/day. The cooling capacity of the AI data center with power usage effectiveness of PUE = 1.4 (40% extra energy needed for cooling). The electrical load of the cooling system is 1350 x 0.4 = 540 kWh/day. In addition to the power needed for the servers, the power capacity of the networking system is 200 kW and constant over 24 hours. The electrical load of the networking system is 200 x 24 = 4800 kWh/day. The total electrical load of both the cooling and networking systems is 5340 kWh/day. The total electrical load for the AI Data center (Servers, cooling, and networking) is 6690 kWh/day = 6.69 MWh/day.

Modleing and Simulation Analysis: Modeling and simulation analysis is used in this study to assess the performance of the proposed clean power system for the AI-data centers. An examination of the technological, financial, and environmental aspects of the proposed green hydrogen-based power system for the huge power demand of the AI-data center is presented in this study. The proposed power model includes an off grid Solar PV, DC/AC converter, electrolyzer for hydrogen production, hydrogen storage tank and hydrogen fuel cell as shown in Fig 2. Prior research by Ghenai et al. [5-7] reports more information regarding the equations utilized for modeling and simulation analysis.

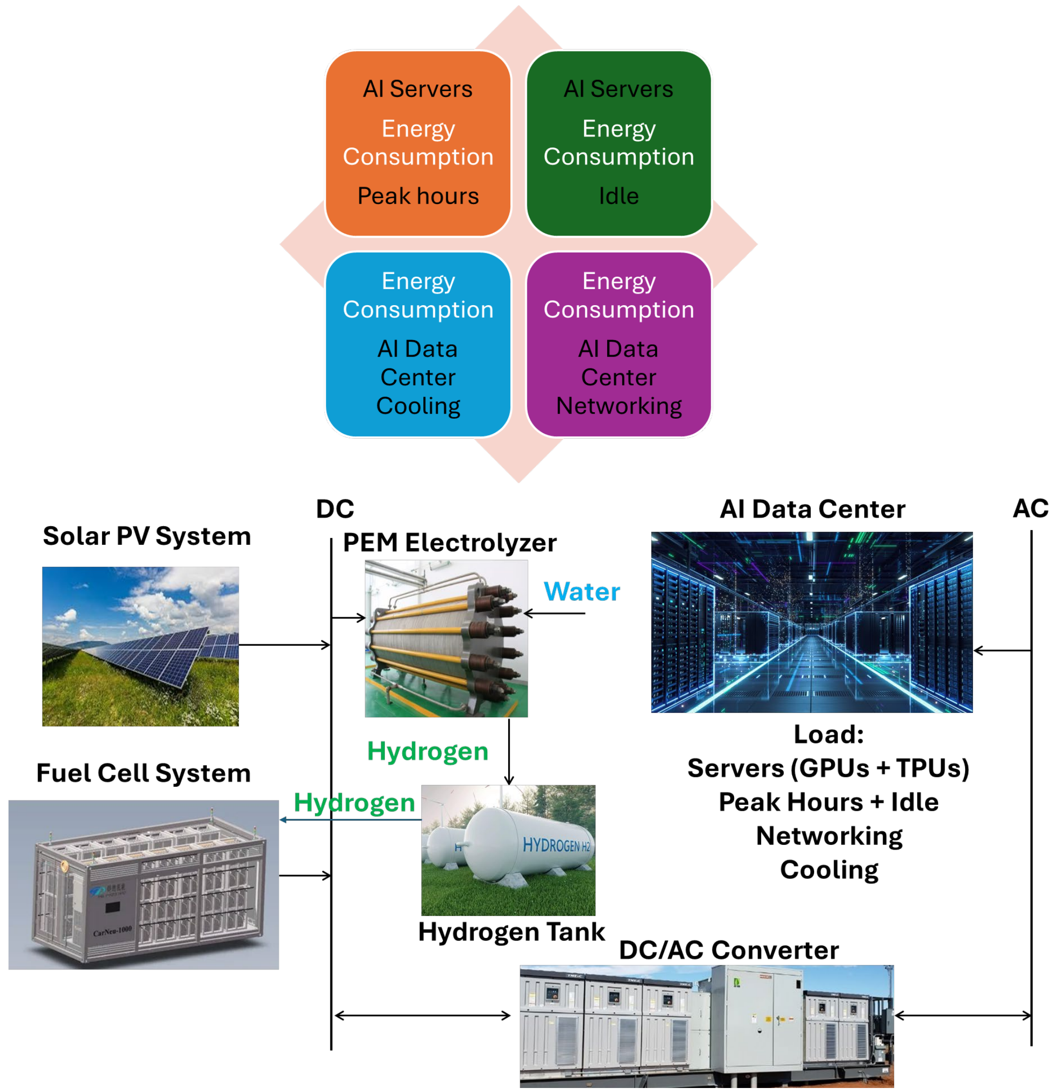

Figure 2. Electrical Loads - AI Data Center (Servers: Peak Hours + Idle, Cooling, and Networking) and Solar PV/PEM Electrolyzer/Hydrogen Fuel Cell Power System Model.

Results and Discussion

Hybrid Solar PV/hydrogen fuel cell power system was used in this study to meet the electrical load of AI-data Center with an average daily electrical energy consumption of 6,690 kWh/day. Green hydrogen was produced using PEM electrolyzer powered with solar PV system. The hydrogen is compressed and stored in hydrogen tank for later use in the fuel cell. The power system architecture has solar PV system with a capacity of 4.95 MW; hydrogen fuel cell with a capacity of 0.5 MW; PEM electrolyzer with a capacity of 1.5 MW; 800 kg hydrogen tank, and 0.484 MW Converter. During the day, 85.9% of the power for the planned system came from solar PV, while at night, 14.1% came from the fuel cell. For the demand or energy consumption, 47.3% of the total electrical energy was used by the AI-data center and the rest was used in the electrolyzer for hydrogen production and excess electricity. The total yearly hydrogen production was 55,175 kg H2/year and the fuel cell consumed 54,877 kg of hydrogen/year. The mean and maximum output from the electrolyzer was 6.30 and 30.4 kg/hr. The specific consumption in the electrolyzer is 49.3 kWh/kg. The maximum capacity of the hydrogen tank is 800 kg with an energy storage capacity of 26,667 kWh/yar and tank autonomy of ~ 96 hrs. The hydrogen tank content at the beginning and at the end of the year is 80 kg and 378 kg, respectively. The average daily and hourly hydrogen consumption in the fuel cell was 150 kg/day and 6.26 kg/hr. The capacity factor of the fuel cell is

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29.1% (nighttime operation). The proposed AI data center's clean energy system uses renewable resources with renewable fraction of 100% and produces no emissions, with almost no capacity shortage (0.09%) as shown in daily profile in Fig 3.

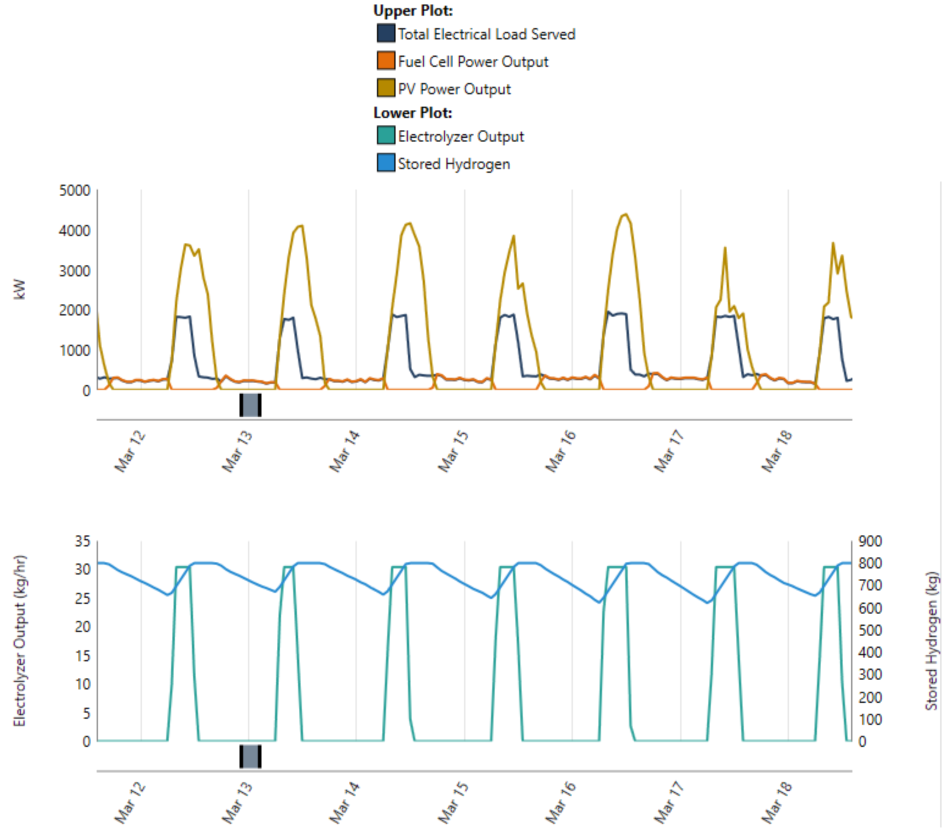

Figure 3. Daily Performance: (a) Solar PV/Fuel Cell Power System (kW), and (b) PEM Electrolyzer Hydrogen Production (kg/hr.) and Stored Hydrogen (kg).

Summary and Conclusions

In this research study, a hybrid solar photovoltaic (PV) and hydrogen fuel cell (FC) power system was used to meet the electrical load of an artificial intelligence (AI) data center that had an average daily electrical energy usage of 6,690 kWh. The electrical load includes the servers (GPUs + TPUs) power consumption during peak and idle hours, the power consumption for the networking and cooling systems. Green hydrogen was produced using PEM electrolyzer powered with solar PV system and the hydrogen was stored in high pressure tank for nighttime use by the fuel cell power system. The results show:

- Optimized clean power system: the system has 4.95 MW solar PV, 0.5 MW fuel cell, 1.5 MW PEM electrolyzer, 800 kg hydrogen tank, and 0.484 MW Converter for DC/AC conversion.
- Power supply: 85.9% of the electrical energy was supplied by the solar PV system and 14.1% by the fuel cell.
- Power demand (electricity conumsption): 47.3% for elctrical power was used by the AI data center and the rest was used to power the electrolyzer for hydrogen production an dpart ot it was excess power. In the event that the system was connected to the grid, the excess electricity might be sold back to the grid (sale of excess power only without power purchases from the grid).

- Electrolyzer performance: the PEM electrolyzer has a capacity of 1.5 MW with an annual green hydrogen production of 55,175 kg H2/year and a capacity factor of 20.7% (most of the electrical power was provided directly to the AI data center from the solar PV system).
- Fuel cell performance: the yearly hydrogen consumption in the fuel cell is 54,877 kg H2/year and the capacity factor of the fuel cell was 29.1% (operate most of the time during the night – energy storage system).
- Cost Analysis: The net present cost of the proposed clean power system is $5,231,011. The levelized cost of elctricity is 0.136 $/kWh and the levelized cost of green hydrogen is 6.02 $/kg.
- Sustainability: Zero emissions from the high-power demand of AI data Center. The renewable power system uses entirely renewable resources with 100% renewable fraction, produces no emissions, and has no capacity shortage (zero unmet electric load).

It is possible to create AI data center that is powered entirely by renewable energy sources by combining clean energy sources with high-efficiency technology and innovative cooling technologies. Direct power purchase agreements (PPAs), on-site renewable producing, energy-efficient artificial intelligence-driven controls, and liquid cooling are some of the primary solutions that can be utilized to reduce water and energy consumption for the AI-data centers.

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