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ARTIFICIAL INTELLIGENCE SYSTEM ON RENEWABLE ENERGY IN SUSTAINABLE DEVELOPMENT

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Abstract
This paper examines the role of technological innovation in artificial intelligence's (AI) pivotal role in advancing renewable energy within the framework of sustainable development. We can enhance the efficiency, reliability, and cost-effectiveness of renewable energy systems like solar, wind, and hydropower by utilizing AI's capabilities in data analysis, predictive modeling, and optimization. Precise forecasting reduces expenses and downtime, balancing clean energy production, weather data, satellite imagery, and sensors for performance predictions. AI facilitates smart grid management, enhances energy storage solutions, and supports the integration of renewable energy sources into existing power grids. Moreover, AI-driven innovations contribute to reducing carbon emissions, optimizing resource utilization, and enabling more accurate forecasting of energy production and consumption patterns. The synergy between AI and renewable energy not only accelerates the transition to cleaner energy systems but also underpins global efforts towards achieving sustainable development goals, including energy security, environmental protection, and economic growth. The aim is to explore the transformative potential to incorporate national grid with renewable energy system based on AI and its critical role in fostering a sustainable future.

Keywords: Artificial Intelligence, Renewable Energy, Sustainable Development, Smart Grid, Energy Efficiency, Carbon Emissions Reduction

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Introduction

Sustainable alternative to traditional energy sources and are becoming increasingly important in the fight against climate change. Photovoltaic panels are used to gather solar energy and turn sunlight into electricity. Solar energy is becoming increasingly affordable, efficient, and a popular choice for homes and businesses. Wind turbines are used to capture wind energy and transform the kinetic energy of the wind into electrical power. Wind energy is a proven, environmentally friendly power source that works best in places with steady, strong winds. In this article, we will explore the advantages of AI in the renewable energy sector and its diverse applications across industry operations. Raheem et al. (2016), Presented evidence on the impact of AI utilization in RE is also investigated; hydropower uses the falling water from rivers or dams to produce electricity. Although hydropower is a well-established and dependable renewable energy source, it may have unfavorable effects on the ecosystem, such as upsetting fish populations. The heat from the Earth's interior is known as geothermal energy. It may be used to raise crops, heat buildings, and produce energy. Although it's limited in its availability, geothermal energy is a reliable and environmentally friendly renewable energy source. Bioenergy is energy produced from organic materials, such as wood, crops, or manure. Bioenergy can be used to generate heat, electricity, or transportation fuels. Bioenergy is a versatile renewable energy source, but it can be controversial due to concerns about deforestation and competition with food production.

Compared to conventional energy sources, RES has several benefits. In the fight against climate change, renewable energy sources emit minimal or no greenhouse gases. Unlike fossil fuels, which eventually run out, renewable energy sources are naturally renewed. Renewable energy is getting cheaper quickly, so many RES are now more affordable than conventional energy sources. Electricity supply can be obtained from certain renewable energy sources, such as hydropower, which is incredibly dependable. Baños et al. (2011)

Although renewable energy technologies offer benefits, there are several drawbacks as well. Depending on whether the sun is shining or the wind is blowing, many renewable energy sources, such as solar and wind, can only generate electricity intermittently. Because of this, integrating them into the electrical grid may be challenging. Storing renewable energy can be expensive and inefficient. This can make it difficult to use renewable energy to meet peak demand for electricity. Transmitting renewable energy from where it is produced to where it is needed can be expensive and inefficient. Certain renewable energy technologies, like wind farms and hydropower, can need lots of land. This could lead to conflicts with other land uses, like agriculture and conservation. Some renewable energy projects can have negative social impacts, such as displacing local communities or harming wildlife. Kardooni, S. et al. (2016). Renewable energy is the energy of the future, notwithstanding these obstacles. The main objective of adopting renewable energy is to address climate change. Using clean energy sources offers environmental and economic advantages. For example, it generates emissions-free energy, reducing greenhouse gases and air pollutants commonly produced by fossil fuels.

Artificial intelligence (AI) is pivotal in modern energy systems, proactively detecting faults to prevent failures and mitigate risks.

Role of AI in improving the efficiency of Renewable energy

Renewable energy technologies (RET) are crucial in addressing the global energy challenge. For instance, wind and solar power are examples of RETs that have gained significant attention due to their potential to mitigate environmental impacts and reduce reliance on fossil fuels. However, successfully integrating renewable energy into energy systems requires comprehensive strategies that consider energy savings, efficiency measures, and sustainability indicators. Moreover, the social perspective on renewable energy autonomy emphasizes the need for specific examples and case studies to understand the challenges and opportunities associated with renewable energy deployment, as demonstrated by the cancellation of wind projects due to public opposition. Additionally, the potential of renewable energy in countries like China and Iran highlights the importance of effectively addressing technology gaps and know-how to harness renewable energy resources. Ahmad Ludin et al. (2018). RETs are pivotal in the global shift toward sustainable energy sources. However, to maximize their potential and accelerate the transition to a greener future, enhancing the efficiency of renewable energy is crucial. AI has emerged as a powerful tool in this pursuit, offering innovative solutions to optimize, monitor, and manage RES.

Literature Review

Artificial intelligence on energy

The electricity generation capacity via renewable sources in 2020 has been increased by 139 GW of solar PV and 93 GW of installed wind, 20 GW of hydropower, and 0.1 GW of new geothermal power-generating capacity that came online in 2020, bringing the global total to around 14.1 GW and 527 MW of ocean power, including tidal capacity (Global Status Report, 2021). However, based on the International Energy Agency (IEA) (2021), RE use increased 3% in 2020 as demand for all other fuels declined. The primary driver was an almost 7% growth in electricity generation from renewable sources.

Artificial intelligence on Bioenergy

Accordingly, the share of renewables in global electric power generation jumped to 29% in 2020, up from 27% in 2019. Bioenergy use in industry grew 3% but was largely offset by a decline in biofuels as lower oil demand also reduced the use of blended biofuels. Renewable electricity generation in 2021 is set to expand by more than 8%, the fastest year-on-year growth since the 1970s. Solar PV and wind are set to contribute two-thirds of renewables growth. Increases in electricity generation from all renewable sources should push the share of renewables in the electricity generation mix to an all-time high of 30% in 2021 (International Energy Agency (IEA), 2021).

Artificial intelligence on sustainability energy

In the same context, after years of development and evolution, artificial intelligence (AI) now began to affect our daily lives deeply and is starting to have a considerable impact on the fields of sustainable growth and development (Vinuesa et al., 2020). In line with this, AI has an essential role in the dramatic increase in RE utilization and contribution to the energy mix, as well as the potential to revolutionize the RE sector. The AI applications and approaches for developing the RE include safety and reliability improvement, cost reduction, strategies to reduce environmental and climate impacts, increase the energy efficiency, expand the RE

market, improve integration of microgrids (MG) and smart grids, produce more accurate predictions of RE, and optimal operation of RE sources (Zahraee et al., 2016). Other methods have been used to improve the tidal energy turbine for better performance and efficiency (Alipour et al., 2020a, b). Therefore, based on the literature studies, the applications of AI for RE operation and utilization (AI-based RE) always had a positive impact on RE utilization, and the negative impact is almost negligible. The RE utilization and AI-based RE have a role in the future of sustainability, either for long- or short-term.

Artificial intelligence on utilization Exhibition

Based on the literature, the potential effects of RE and AI-based RE positively affect sustainable development, while the RE utilization may have some negative impacts. Buonocore et al. (2019). Some recent studies focused on linking the relationship between the achievement of the 7th goal (affordable and clean energy) of the sustainable development goals (SDGs). Swain and Karimu, 2020). However, no research article has systematically examined the degree to which RE utilization and AI-based RE could affect all facets of sustainable development identified in this paper. The method can be characterized by an expert elicitation method: mapping SDG interlinkages (DeNeveand Sachs, 2020). Moreover, we present an assessment attempt, based on the published evidence, which is characterized as an enabler or inhibitor to identify the impact of RE utilization and development on the pursuit of the 17 SDGs and every one of its constituent targets. The evidence on the impact of AI utilization in RE is also investigated, the development of AI, especially its effects on installing industrial robots and the consequent social-environmental implications. For example, Yang and Wang (2023) verify that industrial robot applications have positive effects, enabling trapped countries to cross the middle-income trap. Lee et al. (2022b) show that industrial robot development has positive effects on green technology innovation, and environmental regulation can reinforce the technology innovation promotion effect of AI. Thus, AI development is crucial for social, equal, and sustainable development.

In addition to AI's social impact, the literature also points out that it has positive environmental effects, such as promoting energy efficiency and inhibiting carbon emissions. For instance, Wang et al. (2023) investigate the detailed relationship among industrial robot development, carbon emissions, and energy rebound. They declare that AI development induced by industrial robot applications can help reduce carbon emissions. Yu et al. (2023) also pay attention to the role of industrial robots in low-carbon city development in China and verify the carbon emissions mitigation effect of industrial robot application, and the impact mechanisms are energy efficiency and green technology. This conclusion is supported by Yao et al. (2023), who also find that AI in the energy sector is helpful for enhancing energy efficiency. Li et al. (2022) find that industrial robot application drives the reduction of carbon intensity, and the carbon intensity reduction effect of AI is more prominent in some sectors such as manufacturing, electricity, and gas, which is similar to the conclusion of Olabi et al. (2023).

Material and Method

Material

A literature review from highly regarded journals and reviews of the reports related to the study in the last ten years was conducted to draw meaningful and significant results from artificial intelligence (AI) studies, specifically in the field of power management, maintenance, and control of solar energy systems. This study covered the current trends in AI

as applied in renewable energy and specifically to solar energy systems. This study considered the different techniques for using artificial intelligence to improve solar energy systems' performance and efficiency. Explored in this literature review are those AI techniques and descriptive analysis of renewable energy techniques, such as solar energy.

Method

Photovoltaic Applications and Mathematical Models

Although solar energy technologies differ by many factors, such as the method and the materials used, electricity production from solar energy is carried out in two different ways: direct and indirect. In direct electricity production methods, heat is used both directly and for electricity production, and these include photovoltaic in figure 1, thermoelectric, and ionic converters. In the indirect method, there is steam power obtained using solar energy, and thermal electricity generators and fuel cells using hydrogen obtained using solar energy.

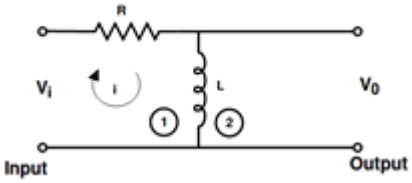


Figure 1 Photovoltaic cell (Süleyman et al 2029)

Applying KVL in o mesh 1

$V_i = Ri + L\frac{di}{Dt}$ I

Apply KVL in mesh 2

$V0 = = L\frac{di}{dt}$ 2

Step 2: By taking the Laplace transform of eq (1) and eq (2) and assuming all initial condition to be zero

$Vi(S) = RI(S) + SLi(S)$ 3

$V0 = SLi(S)$ 4

Step 3: Calculation of transfer function

$$\frac{Vo(s)}{Vo(s)} = \frac{sLI(S)}{(R+SL)I(S)} \quad 5$$

$$\frac{V0(s)}{vi(s)} = \frac{SL}{R+SL} \quad 6$$

Ecometric model

- **AI** enhances the efficiency of each renewable energy source (like wind, solar, and hydro) by optimizing various factors such as predicting demand, minimizing energy loss, and improving energy storage.

- **Sustainable development** focuses on maximizing energy output while reducing waste and loss, achieved by applying AI to better manage renewable resources.

This equation is a simplified representation but provides a foundation for modeling AI's role in enhancing renewable energy for sustainable development.

$$R_t = -(Q1 \times id_{error}^2 + Q2 \times iq_{error}^2 + R \times \sum_j u^j{}_{t-1}^2) - 100d.$$

Here, $Q1=Q2=5$, and $R=0.1$ are constants, id_{error} is the d-axis current error, iq_{error} is the q-axis current error, u^j_{t-1} are the actions from the previous time step, and d is a flag that is equal to 1 when the simulation is terminated early.

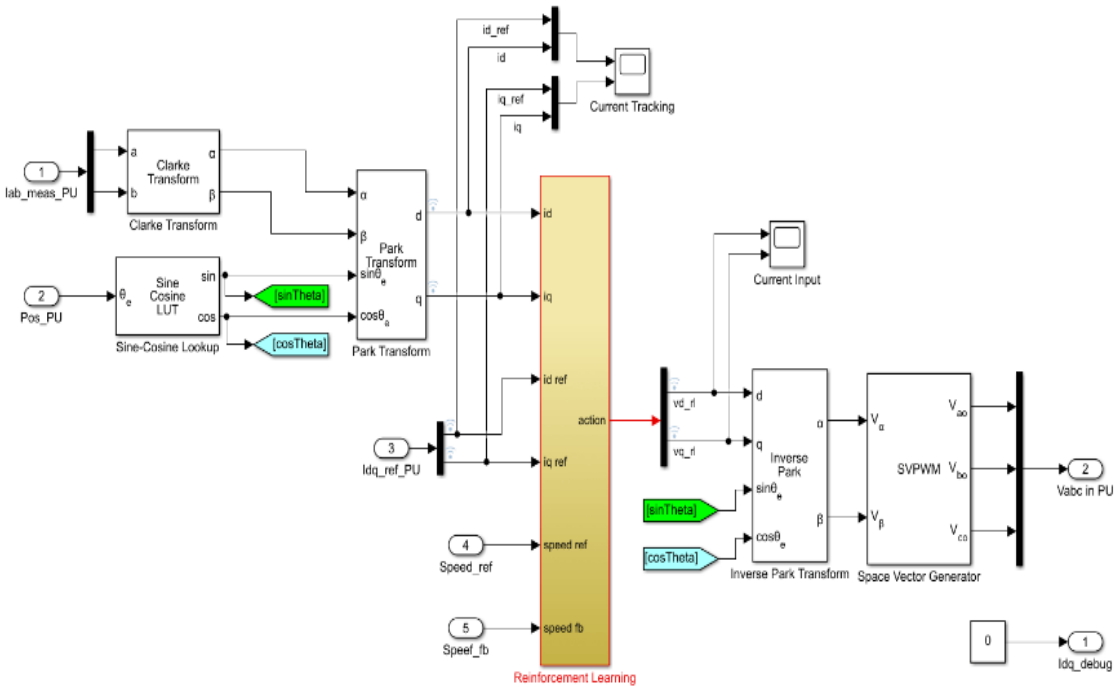


Figure 2 Block diagram of The Reinforcement Learning subsystem model

Create Agent

The agent used in is a twin-delayed deep deterministic policy gradient (TD3) agent. TD3 agents use two parameterized Q-value function approximations to estimate the value (that is, the expected cumulative long-term reward) of the policy in figure 2. To model the parameterized Q-value function within both critics, use a neural network with two inputs (the observation and action) and one output (the value of the policy when taking a given action from the state corresponding to a given observation). For more information on TD3 agents, see Twin-Delayed Deep Deterministic (TD3) Policy Gradient Agent.

The actor and critic networks are initialized randomly. Ensure reproducibility by fixing the seed of the random generator.

Results Analysis

We analyze how AI improves renewable energy performance. The development of AI has the potential to promote more efficient production and innovation. Yu et al. (2023) consider the technology effect when studying industrial robot development and cities' decarbonization, and energy efficiency is also used as a mediation variable in their study. Also, Li et al. (2022) reveal the positive role of AI in improving energy efficiency. Thus, we tend to explore the mechanisms of the technology effect and the innovation effect. Specifically, we use the following equations to conduct mediation effect regressions. Figure 3 explains the various ways adopted for the realization of this research and also the analysis of the data obtained.

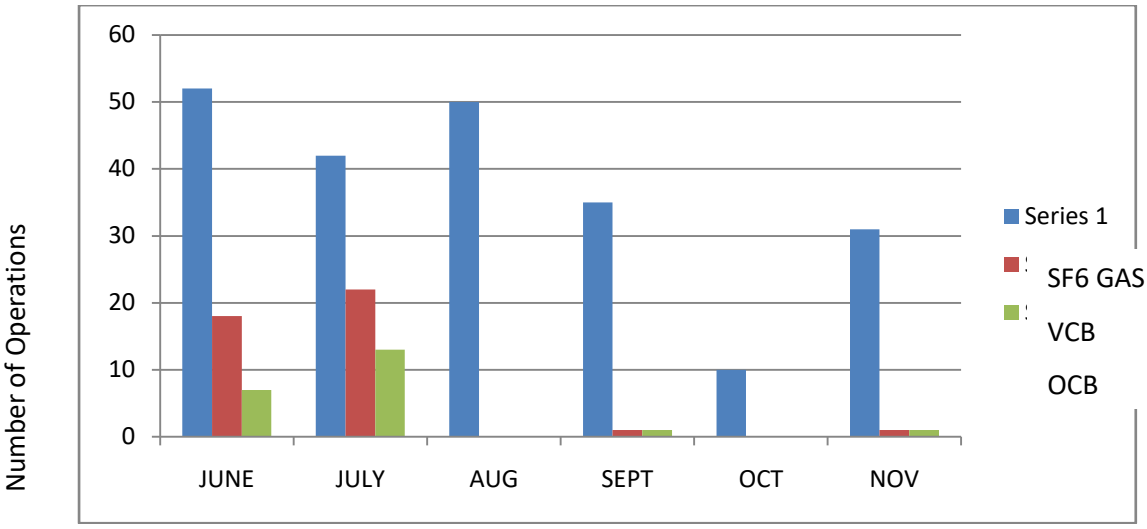


Figure 3 bar operation on AI chart efficiency

Using the bar Inspector, we see that the average execution time exceeds the model sample operation, producing a large amount of overloads that prevent the model from accurately running in real-time. Between June and November, based on the ray of radiation inspection during the rainy season.

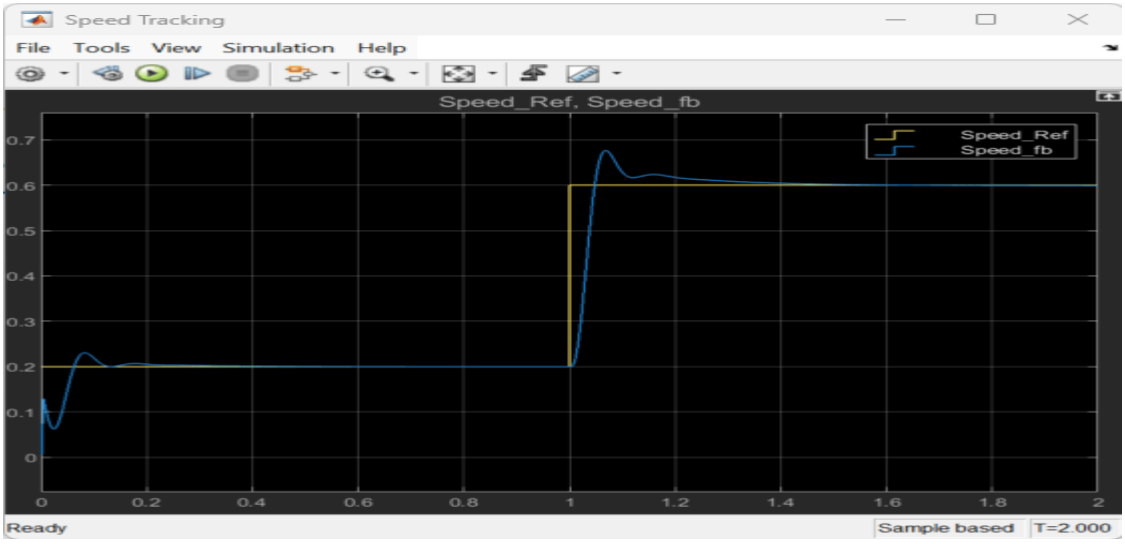


Figure 4 speed tracking of energy

Figure 4 shows an example of closed-loop tracking performance. In this simulation, the reference speed steps through values of 695.4 rpm (0.2 per unit) and 1738.5 rpm (0.5 pu).

The PI and reinforcement learning controllers track the reference signal changes within 0.5 seconds. Although the agent was trained to track the reference speed of 0.2 per unit and not 0.5 per unit, it was able to generalize well.

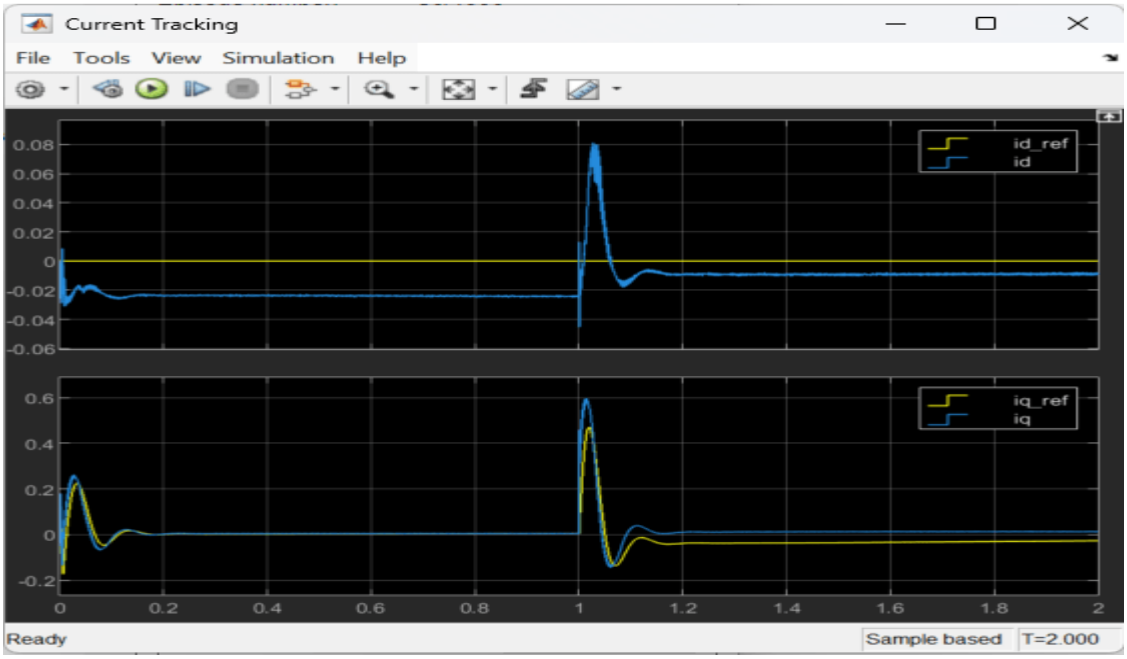


Figure 5 current tracking of AI energy

Figure 5 shows the corresponding current tracking performance. The agent was able to track the id and iq current references with steady-state error less than 2%. In energy operation for improvement of renewable systems for efficiency power supply.

Conclusion

In this paper, the AI applications were presented in different industry segments, such as medicine, agriculture, education, corporations, and the government, specifically in the introductory part. AI applications and techniques in RES were discussed coming from various journal articles. Different authors used several AI methodologies. In solar energy, use ANN methods. These techniques are widely used in different types of solar predictions based on the findings of this review. ANN stood out as the best of these techniques. ANN's specific advantages over its competition include short computing time, higher accuracy, and generalization capabilities over other modeling techniques. This would translate to cost efficiency over other modeling techniques. Future work in AI is a combination of other approaches to further optimize prediction models' accuracy, especially in solar radiation predictions.

Recommendation

Some policy recommendations are given on the short, mid, and long terms in order to facilitate proper integration of renewables and smart grids into the Nigerian electricity grid;

- Off-grid power production study of small and large generators, rural electrification projects not connected to the national grid, private homes with solar PV installations.

The result will show areas that need connection to the national grid and can also support the national grid during peak hours.

- Establishment of a National Energy Databank, which should be up-to-date.

This will aid the government agency and local and international organizations to properly analyze the energy situation in Nigeria.

- Energy education programs in schools, service, and industrial sectors.
- Efficiency standards on home, office, and industrial appliances and equipment.
- Phase out old energy-consuming appliances and electric bulbs with new low-energy-saving bulbs.
- Replace the old metering still in use in some parts of the country with pre-paid Smart meters.

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