

Review on AI Integration With Renewable Energy

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Abstract- This growing demand for carbon neutrality mandates a huge integration of MES or RES. Even MES or RES integration has been made remarkably difficult because of their natural intermittency in highly random and unpredictable modes of operations. Today, MES or RES integration has been made remarkably difficult because of their natural intermittency in highly random and unpredictable modes of operations. Today, MES or RES integration has been made significantly difficult because of their natural intermittency in highly random and unpredictable modes of operations. This study aims to describe the critical role of "Artificial Intelligence (AI)" in MES, which has appeared to be a massively necessary or efficient tool to remove complicated difficulties and problems in MES or RES integration. The complexity and critical significance or importance of "Artificial Intelligence" have been widened; thus, a critical role has been attributed to the activities of energy forecasting, "real time generation, real time optimization, optimal decision, optimal strategy," etc., using different strongly powerful and newest techniques. This paper aims to describe the critical role of important techniques namely "Artificial Neural Networks (ANN), Deep Learning (DL), Fuzzy Logic Control (FLC)" Strategy, and "Heuristic Algorithms: Particle Swarm Optimization (PSO)" and "Ant Colony Optimization (ACO)" Strategy while conveniently ignoring their critical significance or importance. Indeed, the paper will discuss difficulties in MES or conventional operations unconventional grids or strategies because of their complexity complexities with critical significance or importance of "Cyber-Securities" problems. The subsequent critical phenomenon is joined with "Explainability of AI Technology and Quantum Optimization Technology" Integration, "Digital Twinning" Strategy.

Keywords: Carbon Neutrality/Climate Change, Renewable Energy Sources (RES), Artificial Intelligence (AI), Multi-Energy Systems (MES), Grid Stability/Power Quality/Power Quality Disturbances

I. INTRODUCTION

The energy sector around the world has been undergoing a paradigm shift due to the pressing need to address and mitigate climate change. This has been made feasible with the help of carbon neutralization and

consequently requires the success of Renewable Energy Sources (RES). However, RES, despite being a factor of utmost significance related to climatic factors, has certain inherent destabilizing factors like volatility and low inertia.

The conventional control systems employed in power systems were not capable of dealing with such monumental complexity and variability of data sets that might arise in an online smart power system with such a large penetration of RES. Further complexities are added due to the advent of Multi-Energy Systems (MES), an assortment of various networks that manage various energy resources such as electricity, heat, and gas and are designed for better efficiency.

One of the key propositions which can be proposed in relation to the review is that Artificial Intelligence is the only appropriate and efficient measure available to bridge the gap of technology in relation to the given context. Artificial Intelligence presents an intelligence platform regarding the processes of automation, identification, monitoring, and optimization. It enables the functioning of the available system regarding the intelligence-imbedded network of energy imbued with the capability to facilitate stability, security regarding safety, and global transitions in the economics of the energy sector. We will be discussing the current situation of Artificial Intelligence and its points of focus in the article.

II. INTEGRATION OF AI IN MULTI-ENERGY SYSTEM

The use cases of Artificial Intelligence encompass the entire value chain, starting from resource prediction through to the dispatch of complex systems in respect to energy.

2.1 Energy Forecasts and Performance Predictions

In a prediction, there has to be accuracy for it to form a stable system. Accuracy can be achieved in predictions with the help of artificial intelligence in these ways:

Generation Forecasting: Deep Learning techniques such as Recurrent Neural Networks or LSTM can be very helpful in examining the existing data in the time series regarding the speed of either wind or solar irradiation in order to then calculate the subsequent power generation and would be much

more advantageous for the electricity grid planners in order to optimize the time when the RES Back-up Units for power generation should be activated.

Load and Demand Forecasting

The accuracy of the outcomes achieved by the AI models indicates a high degree of accuracy in predicting the consumption patterns related to energy. The area of load matching/peaking would be greatly aided by methods of Demand-Side Management & Demand Response, related to nondiscretionary loads, based on pricing or incentives.

¹ Zhengxuan Lian et.al

2.2 System Optimization and Coordinated Control

The AI system assists in the global optimization framework for various types of energy in that it promotes efficiency and security within the system.

Optimized Dispatch and Unit Commitment: In this area, algorithms provide optimal unit commitment and dispatch by solving highly complex and nonlinear mathematical optimization problems to allow for optimal commitment and dispatch of power generation and energy storage facilities when the rate of RES is high.

Cost Optimization for Operations: AI's efficient methods, like optimized PSO methods Chaotic Darwinian Particle SWOrn Optimization, have been utilized for optimizing controllers and rescheduling conventional generation units and DR resources for resolving congestion issues on or within the limits of the transmission system.

Adaptive Control: Increasing attention has been focused on methods of reinforcement learning (RL) to assist with the process of making decisions in regard to adaptive control to find an optimal method of functioning with regard to actions and reactions with regard to charge/discharge cycles for batteries within a system of renewable energy.

²Kingsley Ukoba1 et.al

III. CURRENT AI METHODS AND THEIR APPLICATION

Contemporary Methods and Their Application – AI There are many AI approaches, incorporating artificial neural networks and the biological heuristic, that play a highly significant role in addressing the difficulties arising from the implementation of RES.

3.1. Artificial Neural Networks & Deep Learning

Being heavy users of nonlinear connections themselves, ANN systems find numerous applications in:

Fault Diagnosis and Monitoring: Pattern recognition for traffic to allow quick fault diagnosis.

Surrogate Modeling: Using ANNs, a high-fidelity model can be approximated. This implies that ANNs serve as surrogates for models during the optimization process. This lowers the computation cost by over 100 times for the optimization algorithm. This results in real-time optimization with high accuracy.

3.2 Heuristic Optimization

"These population-based optimization algorithms are designed to address efficiently the large-scale, non-convex optimization problems, like the optimization problems of interest in this paper, since they know that.

Particle Swarm Optimization

More often used for optimum sizing of Hybrid Renewable Energy Systems (HRES), optimum functioning schedule, and accurate tuning of PI controller of power converters for better dynamic response.

Ant Colony Optimization Algorithm The ant colony optimization technique can be applied successfully in dealing with complex geographical problems, such as the optimization of wind farms on land. Modeling this problem, the search process executed by the technique relies on configurations involving minimum aerodynamic wake losses that would offer the highest production of electricity.³ Ezekiel Ezekiel Smart1 et al.

3.3. Fuzzy Logic

FLC is an adaptive system, which is also nonlinear, and its use is highly significant in the context of managing the ambiguity and uncertainties that exist while operating the RES system. FLC is able to support the translation process that takes place from linguistic terms to verifiable parameters, which is a highly consistent system to control processing. It is highly efficient in energy managementplanning, which improves the overall charge state of the modules used in energy storage, increasing the lifespan of the battery.⁴Raghu Raman 1 et al.

IV. CHALLENGES AND FUTURE PERSPECTIVES

However, there exist some hurdles which have to be overcome before it can realize its true potency.

4.1 Current Limit

Computational Complexity & Energy Consumption: The training of complex models is so resource-intensive that these have high computational complexity. Thus, the problem of energy consumption is a major concern, which apart from disrupting the environmental harmony, needs to be minimized on environmental grounds. **Model Interpretability (The Black Box Problem):** The lack of interpretability in advanced models of AI/ML has become an issue in critical infrastructure. The fact that these models are not easily interpretable, contributing to the difficulty in trusting decisions made with the help of AI, is an issue related to them. **Vulnerabilities in Cyber Security:** The interoperability of smart devices with AI has increased the risk factor. Vulnerability to attacks like poisoning attacks in AI may likely impact the stability of electrical power supply and the greater level of privacy. **Quality of Data:** The data hungry characteristics of artificial intelligence models have made them prone to faults and/or biasness or possibilities of having inaccurate data if proper data is used. **4.2. Research Explainable AI (XAI):** It has become increasingly important that technology pertaining to Explainable AI be developed. The next generation of models needed are traceable or interpretable models providing explanation related to every decision made by use of its control/dispatch system. **Integration of Quantum Computing:** Quantum Computing may hold the key to the optimization challenges being encountered in power grids. This would be achievable in a 'Very Short While,' making global MES optimization possible in the 'True Real-Time.' **Decentralized and Autonomous Systems Federated Learning (FL):** FL could be utilized to offer the capacity to train models for AI without the need to share data with cloud services; therefore, the information on concerns about energy could be excluded. **Digital Twins (DTs):** A virtual copy or model of the energy system could potentially be applied to services for predictive maintenance, safe analysis, or risk levels by means of AI technology. **Policy and Regulation:** There must be an established or announced "Regulatory Framework" that would be applied to answer ethical criteria, protection of data, or security levels that would be suited for enhancing the application of "AI" in the "energy sector."⁵ Kon "The Quest for Carbon Neutralization" promotes a "Paradigm Shift" concerning the relationship/implementation of "RES" at a "Large" scale that cannot be implemented/facilitated from a purely technical standpoint without resorting to "the powers of Artificial

Intelligence." AI technologies add strength or the full "intelligence power" that is unused and unmet within the "efficient forecasting, dynamic optimization, or control" necessary for the transformation of the "variable resources" into the "Constant Resource" that is the "complex MES." Even in such areas like interpretability and computational complexity, full of unknowns and undefined areas of solutions of research problems, hopes for the future are based upon advancements of XAI and use of capabilities of Quantum Computing and Fed Learning. ⁵Dariusz Mikołajewski et.al

REFERENCES

- [1] Artificial intelligence powered large-scale renewable integrations in multi-energy systems for carbon neutrality transition: Challenges and future perspectives, Zhengxuan Liu^{a,b,*}, Ying Sun^{c,*}, Chaojie Xing^a, Jia Liu^{d,e,f}, Yingdong He^a, Yuekuan Zhou^{g,h,i,*}, Guoqiang Zhang^a *Energy and AI* Volume:10,2022 DOI: 10.1016/j.egyai.2022.100195
- [2] Optimizing renewable energy systems through artificial intelligence: Review and future prospects, Kingsley Ukoba¹, Kehinde O. Olatunji¹ Eytayo Adeoye², Tien-Chien Jen¹ and Daniel M. Madyira, *Energy & Environment*, Volume: 35 DOI:10.1177/0958305X241256293, Pages:3833–3879, 2024.
- [3] Artificial Intelligence (AI) in renewable energy forecasting and optimization Ezekiel Ezekiel Smart, Lois Oyindamola Olanrewaju, Joseph Usman, Kabiru Otaru, Dauda Umar Muhammad, Prince Nnamdi Amalu and Emmanuel Toba Popoola , *World Journal of Advanced Engineering Technology and Sciences* Volume: 15 Pages:1100–1112 ,2025 DOI:10.30574/wjaets.2025.15.2.0300
- [4] Navigating the Nexus of Artificial Intelligence and Renewable Energy for the Advancement of Sustainable Development Goals, Raghu Raman, Sangeetha Gunasekar, Deepa Kaliyaperumal and PremaNedungadi *Sustainability*, Volume: 16 DOI:10.3390/su16219144, 2024
- [5] Leveraging Machine Learning in Next-Generation Climate Change Adaptation Efforts by Increasing Renewable Energy Integration and Efficiency Izabela Rojek, Dariusz Mikołajewski , Marek Andryszczyk , Tomasz Bednarek and Krzysztof Tybure *Energies*, Volume:18 DOI:10.3390/en18133315, 2025