Leveraging AI and Industry 6.0 for Greater Efficiency and Innovation Through Sustainable Energy

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Edited by

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ABOUT THE BOOK

This edited book on "Leveraging AI and Industry 6.0 for Greater Efficiency and Innovation Through Sustainable Energy and Sources-Solar, Wind and Green Hydrogen" pushing the transition to a sustainable energy future even faster. This book explores the transformative potential of AI-powered predictive analytics, automation, and intelligent decision-making systems that are helping to make energy production, storage, and distribution stronger, cheaper and more sustainable. The book explores major topics related to AI in Energy, including but not limited to, AI-enabled smart grids, digital twin technology, machine learning for predictive maintenance and the contribution of the IoT to the maximization of energy efficiency. It covers on vital socio-economic and regulatory facets for a well-rounded view of the global energy transition.

There is a fundamental transition in global energy driven by the intersection of Artificial Intelligence (AI) and Industry 6.0. With a worsening climate change problem and an increasing need for sustainable energy solutions, new ways to optimize renewable energy resources like solar, wind and green hydrogen are crucial to meeting energy needs. The technologies speaks the language of Industry 4.0 and this is the story of how AI is increasing automation brought forth in Industry 4.0 but changed in Industry 6.0 where intelligent automation, augmented human-machine collaboration and cyber-physical systems define new realities in how energy is produced, managed and distributed. Artificial intelligence is pivotal for improving efficiency, forecasting energy needs, and integrating renewables into smart networks. This edited book provides a unique overview of the impact of AI on Industry 6.0 and sustainability with extensive information on cutting-edge technologies and their usage in practical scenarios.

It provides insights into the complexities of AI-accelerated energy transition, such as predictive maintenance powered by machine learning algorithms, digital twin technology for energy systems optimization, and the emerging Internet of Things (IoT) which embodies autonomous smart grids. It also explores how AI optimizes green hydrogen production to increase its potential as a decarbonization option for industries. In addition to technical advancements, this book also covers policy frameworks, regulatory challenges, and socioeconomic implications of AI-infused energy solutions. It offers a holistic view by combining views from researchers, industry and policymakers involved in these emerging fields. It is a valuable reference for academics, energy professionals, and sp policy makers seeking to accelerate the transition to a greener, more resilient energy ecosystem. It provides valuable insight on how can better optimize AI and Industry 6.0 will shape future renewable energy era. It is a core contribution to seek energy security, carbon neutrality and a greener planet by connecting technology and sustainable practices.

PREFACE

AI is driving of innovation but it need the most reliable and trusted solutions to reestablish and channelize the energy of evolution into wealth creation. This book “Leveraging AI and Industry 6.0 for Greater Efficiency and Innovation Through Sustainable Energy and Sources-Solar, Wind and Green Hydrogen” explores how AI interacts with renewable energy sources such as solar, wind and green hydrogen to enhance energy sustainability, innovation and efficiency. With embracing collaboration between humans and machines, Industry 6.0 is enabling the differentiation of energy generation, storage and distribution as the world demands energy on-demand while bringing this from traditional fossil-bound processes to renewable, environmental friendly processes.

The transition to clean energy is not only a technological evolution; it is now a strategic necessity to mitigate climate change and guarantee energy independence. These comprise AI-powered predictive analytics, smart grids and automated energy management systems that collectively are optimizing the use of renewable energy, minimizing waste and improving resilience. Specifically, algorithms powered by artificial intelligence can improve solar panel efficiency, refine wind turbine performance, and enable rapid scaling of green hydrogen production, all of which help to make these forms of energy more feasible and cost-effective. This book explores how AI enable each of its innovations like machine learning, digital twins, IoT-enhanced sensors, stimulate energy transitions in Industry 6.0 with increased intelligence, adaptability and sustainment to ecosystem.

So, in addition to technical advancements, the book also explores the socio-economic and policy dimensions of AI-driven renewable energy systems. It emphasizes the importance of balancing technology for good while also suggesting regulatory frameworks and ethical considerations. This work provides an essential guide to researchers, policymakers and industry leaders grappling with the myriad possibilities associated with Industry 6.0, as countries work toward achieving universal carbon neutrality and energy equity, while moving toward a global cohesive agenda for clean and sustainable energy solutions.

CHAPTER 1

ASSESSING THE ROLE OF ARTIFICIAL INTELLIGENCE IN RENEWABLE ENERGY SYSTEMS

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1 Abstract

Despite the efforts to bring the rise of AI into among the much sustainable energy and decent jobs being created, those trained in the use of AI to effectively develop sustainable energy and contribute to the elimination of local and global environmental degradation, very detailed plans for such implementation have not been quantified; almost every published paper has been vague. Preferred applications of AI on renewable energy sources are fragmented across different platforms with potential uses; apparently, only a few have highlighted systems for such steps to integrate overall energy planning. Precisely, the studies scrutinizes a range of AI directions that have been employed in the field of renewable energy such as solar power, photovoltaics, microgrid embedding, management of battery-based power, wind turbine technology, as well as geothermal power generation. He also tried to delve into and provide a thorough knowledge of AI's contribution to revolutionizing renewable energy systems through examination of recent technical breakthroughs made, major research

findings as well as illustrative case studies. Indeed, the present work not only evaluates the constraints hindered under this branch but also tries to build plausible ways to address the same.

Keywords: Artificial Intelligence, Renewable Energy Technologies, Energy Efficiency, Technological Advancements, Sustainability

2 Introduction

Renewable energy use has an immediate link to the progress of societies. Life's necessities have gone on a rise owing to the ever-ballooning world population alongside moves towards urbanisation and overall economic progress. That goes to fuel and power production in numerous industries relying upon conventional forms of energy like natural gas, coal, and petroleum to meet its burgeoning demand more and more day after day. Furthermore, there will be a presentation of the future trends and possible developments in artificial intelligence for renewable energy breakthroughs, which will work excellently for scholars, practicing engineers, and industry experts as far as improving the domain and removing the already existing obstacles (Nahar, 2024, 201).

The reliance on fossil fuels has depleted not only resources but has also played a major role in changing the climate and warming the earth through the massive production of greenhouse gases (GHG). The climatic changes contributed through its destruction, for instance, rising ocean levels, glacier retreat, deforestation, air and water pollution, ozone layer depletion, radioactive gases that induce the greenhouse effect, acid rain, and environmental damage, all pose severe threats to both the economy and society. The agency further warns in its report that the GHGs emitted from energy consumed would increase the temperature by 6°C from where it was before, causing the most significant environmental damage yet. Indeed, the practical removal of harmful environmental changes and the potentially brighter energy future in line with clean and green energy for the welfare of mankind are set out as reasons for setting good transition plans (Aitkazinov, 2023, 117-119).

More on alternative energy sources like renewable energy (RE), which is seen as the most important answer: Renewable energy will reach 10,800 GW globally by the year 2040, as the International Energy Agency (IEA) forecasts.

Breaking away from the crowd of fossil fuels, these renewable systems-solar, wind, hydro, biomass, and ocean power seal the preference because of their duration a minimal ecological footprint, promotion of cost efficiency, and the long endurance these systems could offer to both a facility and the developer. Recent developments have harvested energy generation and distribution for earth-friendly living. Solar and wind energy sources-photovoltaic and wind turbines-provide the most forward-moving parts of a renewable energy system (Goel et al., 2022).

An energy revolution powered by sustainable renewable energy technology will have a potential to revolutionize the electricity industry. It may promote effective cost management of electricity, improve the adaptability and resiliency of energy systems, upgrade old infrastructures, mitigate CO2 emissions, provide dependable power delivery in remote areas, and decrease ecological impacts. Energy storage systems (ESS) have evolved significantly over the years in efforts to meet emission reduction and energy efficiency requirements. These advances highlight the old prescription to upgrade the accuracy in forecasting RE, essential for the functional optimisation of the power system (Mao et al., 2023, 802–808).

Advances in technology have made renewable energy systems more accurate. Through creation of intelligent devices and future software, artificial intelligence is an advanced idea. In the olden day, mechanical Engineers made simple algorithms of choosing among an array of choices, such as data collection and monitoring for renewable applications. It's very likely and can be true: AI has evolved greatly in the past years, bringing great change to people daily live and in sustainable growth; it can include different traditional applications in sectors such as energy, agriculture, learning, health care, security, and industry and in the arts (Nepal et al., 2022, 4911).

Artificial Intelligence (AI) has powerfully influenced the RE policy and business by simulating scenarios, policies to analyse this efficacy, and forecast economic results. It helps to monitor ecosystems, calculate the carbon footprint of energy generation, and optimize resource utilization so as to reduce environmental impact. AI can be used to help predictive modelling by promoting greater accessibility of clean energy for more marginalised communities as well as improving relatively less explored renewable innovation for the generation of energy (eg. tidal and wave). For solar power, meta-heuristic methods based on AI improve system performance, and they also have integrated algorithms to enable forecast of the wave energy characteristics. Optimization of the advanced biofuels that minimize the emission from transportation and industrial sources is now currently available through methodologies. Such projects include the employment of an AI-based previous artificial brain, which predicts the solar still's performance, elevated energy utilization and water produced. Predictive maintenance, more energy-efficient performance, more environmentally friendly, development for intelligent grids and microgrids, better solar stills, and integration to RE systems have all become examples of climate change. These developments establish AI as a force that transforms the landscape for renewable power scenarios (Kothari et al., 2021).

Investigating AI integration with RE would improve energy technology for renewable technology and would save, monitor, and oversee it. The research focuses on AI-driven development in the renewable energy systems for solar, wind, hydro, and geothermal power using selected case studies using diverse geographical factors. These remarkable applications combined with the comparative study of established ones could guide us to our best approach. Some of the difficulties discussed while exploring the challenges are using Artificial Intelligence for managing and evaluating data and data security issues in RE systems, ways to greatly solve them, and future trends, among others. This research work is for academics and engineers as it gives a very slab but detailed overview on the applications of artificial intelligence in viable sources of energy, sharing thousands of practical outcomes and suggestions for future studies (Moraga et al., 2022, 134-149).

3 Renewable Energy Sector Without the Influence of Artificial IntelligenCE

Even as intelligent agents are shaping the energy industry in general, alternative energy sources have found ways to be developed and constantly renewed (Georgiou, 2019).

The use of technology for increased efficiency, lower costs, and issue resolution in concerns in renewable energy are now changing. This has some limitations to be sure. The traditional way of data analysis and decision-making only offers very slow development: it is not as prompt as one might think in drawing conclusions or forecasting from it. The use of AI in renewable energy was more expensive for making massive investment into infrastructure, data acquisition, and the development of algorithms and so on, thereby causing obstacles for developing countries to make the adoption. The concern about data privacy and security threatened to become instrumental in endangering the generation of power-by differences in distribution. Conversely, AI could have drastic effects on the renewable energy business by improving processes and may lead to an overall increase in output. During that period, the research confined itself to using the sources of renewable energy. New renewable energy resources were discovered for use in conservation (Karim et al, 2017, 1296–1306).

This report was - given before- into the sequence of those from 2017 and first explains the prevailing state of power accessibility in those urban disadvantageous regions, also clearly specifying the state of no power in Korail slum in Dhaka. It is indicated in black and white by the presented facts of the problems and that growth is one of these avenues considered very necessary to the design of electrical energy plans, for example, rooftop solar photovoltaic or generating electricity using solid waste and the phasing out of incandescent light bulbs. In addition to ensuring technical knowledge regarding the methods, these programmes typically create a double-edged advantage: 1) the availability of additional power and 2) opportunities for surplus generation and thus cost savings. Another study investigates the effects of environmental regulation on sustainability: retesting as well the role played in sustainable development in this context by research and development on renewable energy (RERD), technical changes, and truly great economic performance. Wavelet methods are also utilized in the study at the end to argue that high levels of funding in RERD, strict legislation, and the adoption of ecofriendly technologies are crucial for conservation of the environment. The study also reveals the existence of significant relationships such as those between CO_2 emissions, change in technology, and growth in the economy (Marquez, 2023, 1).

4 Artificial Intelligence in Renewable Energy

1. Renewable Energy types

The research emphasizes the constant-comprehensive necessity of innovation and adaptability of renewable energy systems (RE) to impart electricity by way of innovative technologies into the systems. The enhanced RE system can be fuelled by a single or a mixture of any fuel resources, which is termed hybrid technology. The single-source system is typically solar, bioenergy, hydro, geothermal, wind, ocean, and also hydrogen energy; the latter hybrid is the blending both of the renewable and cruder energy sources such as small gas or diesel turbine made up of hybrids with electrical storage. The common hybrids include various form photovoltaic-wind-diesel and hydro-wind-photovoltaic systems with fuel cell system to create power (Mazzeo et al., 2021, 120999).

2. AI tools and techniques

Different types of learning techniques have been copied through AI-NN, Numeric, and Progressive Learning and are more widely studied. In research, neural networks (NN) among others support vector machines (SVM) forms the most often-used arrangements. Other algorithms that are always highly favored are decision trees, random forests, logistic regression, linear regression, nearest neighbour, and hidden Markov. The use of artificial intelligence has largely increased interest in the application of renewable energies (RE) excelling in power sector hence attracting more attention to areas like hydro, wind, geothermal, solar, and ocean power, as well, since their productivity and extendibility could be increased greatly (Liao et al., 2021, 774–802).

3. AI role in RE

Renewable energy (RE) technologies have been a major focus for research and development in the contemporary era in various industries given their advancing expansion. Great strides have been made with the advent of intelligent and sophisticated technologies, more particularly AI-powered solutions, in dealing with the mounting problems and opportunities in the real estate world. The areas where this is being put into use are in power management, photovoltaic solar systems, and efficiency and control of energy. In the most recent researches, the focus was put on further increasing the use of AI in RE applications, such as the estimation of solar radiation, the estimation of the energy taken into solar systems, predicting wind speed, building modeling for heating, forecasting long- and short-term power, sizing solar power generation, and predicting power consumption for specific regions (Akhter et al., 2019, 1009-1023).

As the integration of artificial intelligence (AI) and the Internet of Things (IoT) fosters modern Renewable Energy systems, progress in RE technologies has emerged in line with improved efficiency, strength, and flexibility. Nowadays, AI finds its application in quite many renewable energy technologies, including wind, hydro, geothermal, and solar energy, accordingly. Some of the progress can be credited to technologies like artificial intelligence (AI) that significantly contribute to making opulent Renewable Energy projects that will possibly become highly principled modern renewable energy systems. Perceptions of the usefulness of advanced recommender algorithms in PV system performance are explored further in such research. Support for renewable energy is also in recognition that renewable energy technologies (RETs) can now become fast becoming cheaper and supported less heavily for subsidies than during the earlier time, providing full cost recovery and profitable growth. This is of course based on the perception given by performance additions through time aside from cost reductions.

4. Applications of AI in RE

On several types of renewable energy, artificial intelligence (AI) has almost immediately become a significant aspect: hydrogen, hydro, solar, geothermal, wind, bioenergy, ocean, and hybrid systems. Using artificial intelligence, weather-based electricity generation can be foreseen by different machine-learning algorithms and statistical methods such as p-values and confidence bounds. Keeps the grid stable. Besides repairing systems, AI heavily contributes to predictive maintenance regarding energy infrastructure. It also brings down time, maintaining steady energy. The physical uses of AI in this case are design, optimization, management, calculation, dispersion, and legislation for renewable energy. Five major renewable energy technology areas will be reviewed in this chapter: solar energy, photovoltaic (PV) technologies, solar microgrids, wind turbine optimization, and geothermal energy, and the mind open to understanding numerous applications of AI in each of these fields.

A) AI applications in solar energy

Students or individuals who only learn or access the proxy website for studying courses or accessing any blocked website is manually and independently sought-after. They use search engines by familiarizing themselves with the domain name, since no university proxies are available for students to choose from (Alzitani et al., 2019). One such trend for getting access to blocked websites is the increasing admiration of using online proxies as sites that assist users in unblocking visitation of websites quickly. Online proxies are necessary while browsing since there are certain requirements for some websites. Most institutions use security software that makes it hard to browse, particularly inside a restricted network; others even engender problems if any process is being done online. Eventually, the design of simulation systems that are controlled by AI would bring along quite large-numbered and adequately defined benefits. On the solar energy simulation front, these would work in lieu of traditional procedures; they are found to be far more affordable than any prevailing alternative in gruelling and cumbersome multivariable problems at a minimal level of computing resource use, so they can just be deployed without knowing the exact internal system mechanisms (Tawalbeh et al., 2021, 143528).

It has been common that Artificial Neural Networks (ANNs) are considered to be the most popular AI-based research among academics around the world. Accordingly, several studies are found to use the Backpropagation Neural Network (BPNN): to engage the solar, electromagnetic, illuminance, daily temperature, water heater and solar radiation, system operation, building use of energy, beam radiation and maximum power output from high concentration PV modules. Furthermore, Adaptive Neuro-Fuzzy Inference Systems (ANFIS) have been used to predict PV power supply, estimate clearness index, estimate hourly global radiation, predict power in solar photovoltaic installations, and evaluate the operation of solar tower power plants. Several examples of combinations of different methods are employed in several studies to improve predictability. Comparisons involve intensity measurement, such as the Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), which are frequently utilized to measure different model forecasts vis-a-vis live results. These are common assessment measures in the environment and forecasting fields that are used to assess the efficacy of models (Nam et al., 2020, 109725).

B) AI-driven enhancements in PV technology

The convergence of geospatial and machine learning technologies is expected to expand the flexibility and intelligence of solar photovoltaic systems. However, harnessing photovoltaic potential requires more insights and understanding - defined by interdisciplinary research, even adaptation of materials science and computational analysis on the practical experience obtained in critical areas such as silicon and thin-film solar cells. Odd as it might seem, the researchers and engineers are passionate about creating new approaches through "artificial intelligence" to make PV technology affordable, workable, and above all productive. Under the drive of AI breakthroughs, one finds a new diagnostic toolkit given to scientists for the optimization of solar cell performance, thereby a major upgrade in their usability. Today's reports indicate the beginning of a whole new era in renewable energy development because of artificial intelligence.

AI made some biggest impact in the transformation of photovoltaic (PV) energy systems. With new ways of measuring using AI algorithms and modern data analytics, it will be possible now to more precisely monitor the changing influences on solar performance like light intensity and temperature conditions and interference from shading. So, the AI techniques can help bring to the optimum level the real-time monitoring and analyses of the parameters in the operation of solar installations. The AI-driven optimization has helped in improving the stability and reliability of the power generation functions in the PV systems, hence significantly enhancing the overall efficiency (Naser and Abdelbari, 2020).

Artificial intelligence has made a huge difference in forecasting solar irradiation and assessment of resources for the attainment of better overall energy management and grid connections. If AI is incorporated, it will also generate short-term and long-term solar irradiation predictions from historical data and future weather forecast information, which will ensure the optimization of the energy output and system stability. Thus, the energy manager and systems operator will minimize variations in solar-generated electricity.

In addition, AI is gaining attention as technology to maximize solar cells by accumulating massive data for analysis. AI is expert in identifying even complex patterns or trends within vast datasets on the efficiency of solar cell supplies and designs. It’s about enhancing machine learning algorithms to ease the job by zeroing in on the most crucial factors leading to solar cell productivity, leading to a better understanding and, above all, better production of solar energy. These steps help professionals design and improve solar cells (Onwusinkwue et al., 2024, 2487-2799).

Precisely identifying modeling parameters for photovoltaic (PV) cells plays a key role in the complex modeling of PV cells and is becoming an active area of research. Various studies are thus being carried out aiming at realistic and practical approaches to get around the same question. Roughly speaking, these two approaches can be classified into analytical based tactics and meta-heuristic algorithms.

Among other things, algorithmic strategies include the use of very skilful software, with a myriad of time-honoured algorithms available on procurement by commercial interests. It can be anticipated that the models of these products will incorporate any of these strategies in the most effective way. On the other hand, the one reason for the high popularity of meta-heuristic algorithms is based on advances in swarm intelligence and computer-based techniques, especially in resolving complex optimization problems and uncontrollable disturbances. One of the most important advantages of meta-heuristic algorithms is that they avoid needing an accurate model. This has led to a reduction in the cost of computing. In recent years, research on meta-heuristic techniques for accurate prediction of PV cell performance has increased alarmingly. These systems combine artificial intelligence (AI) with physical-based mechanisms to give probably more reasonable predictions for PV power over various time steps: from longer through intermediate times. As far as forecasting errors are concerned in terms of various techniques, including RMSE, MAPE, and MAE, all other techniques and algorithms focus more on minimizing such errors than this particular set of methods does. Quite a few published articles tackle detailed analyses of these methods, including synthetic generated results. These are based on bio-inspired classes and classified in three ways: bio-based, physics-based, and even mathematical-based algorithms (Fan eta al., 2023, 13493).

For bio-inspired algorithms, these techniques include, among many others, flower pollination, optimization using bacterial foraging, and grey wolf optimization. In physics-based algorithms, there are procedures that operate by using particle swarm optimization, optimizing processes wind, optimizing processes water cycle, Lozi map chaos optimization, scale mutation optimization, and simulant steeping. On the other hand, the methods predominantly based on mathematics such as that of the shuffling complex evolutionary Jaya algorithm or that of the Structure Search Algorithm, are used with algorithms that bear similarity with the classical derivation of mathematical-based meta-heuristics (Mahapatra et al., 2021, 100036).

C) AI in solar microgrids (MGs)

One of the weapons in their current power system attack is distributed generation (DG) and storage system, and especially the microgrid. MGs connect conventional and renewable energy sources, loads, and energy storage devices. Their flexibility, sustainability, self-sufficiency-these all together make MG very useful in improving power system performance measures, in particular, dependability and resilience. The success of microgrid research has always been coupled with problems on the design and installation side. And almost more challenging is that MG is prone to their own constraints in load management, renewable energy sources, and energy source management, as well as immediate swings in demand.

Furthermore, in this way, another catalyst in modern-day electricity systems is that the integration of disparate components, as exemplified by conventional or smart meters, distributed energy resources (DERs), energy storage systems (ESSs), electric cars, and Internet connections, induces huge data volume. The problem of data overload has resulted in efforts by scholars to devise complex methods of overcoming these scopes, such as artificial intelligence (AI). The issues related to handling and analyzing large amount of data are not addressed adequately by the traditional approaches of simulations. This chapter provides a review of recent research on artificial-intelligence-based approaches toward greater performance, stability, reliability, and security of MGs.

The AI-based approaches in power systems are the largely categorized, and expert systems (ES) are the most commonly used technologies in this category, and collective techniques in the field of ML algorithms are implemented in AI systems.

D) AI in wind turbine optimization (WTO)

Wind turbines have been deemed an essential element of power distribution structures in the current environment as it has experienced tremendous global growth in usage. With the approaching wind rolling on the windmills, this really makes a direct impact on them as they must determine ideal configurations for the most efficient harvesting of energy by studying wind characteristics and potential site placements.

A group of researchers has highlighted the implementation of effective wind turbine control systems, thus noting that due to large scale and complex electrical systems associated with their operations, these systems serve to eke out the much-needed additional benefits in boosting efficiency, and revenue is thereby generated for the various energy companies.

The development of operational controls for massive wind turbine facilities proved challenging because the wake instability-related phenomenon proved particularly difficult to overcome. When wind turbine blades operate they generate an exclusive oscillation pattern in the wind stream which produces wake turbulence within the boundary layer. There are also possible losses in the airflow from this disruption. In designing controllers for a wind farm, it will necessitate a more profound study on the effects of wind power in the field as such (Tao et al., 2023, 13345).

Scientific research has openly states that one of the ways wind power potential can be exploited completely is by means of its remote monitoring and management of wind turbines. Moreover, wind power unavailability cases in the farm are because of mechanical breakdowns, problems with its electrical parts, and extreme temperatures. It is beneficial to operating constraints on the processes across these limits-responding systems, even though the cycles and swings of wind currents vary significantly over time.

To aid in addressing these concerns and making headway in prediction, control, and monitoring of wind turbine systems, researchers and technologists have used the power of Artificial Intelligence (AI) and its Machine Learning techniques. Artificial Neural Networks (ANNs), Support Vector Machines (SVMs), and Swarm Optimisation Algorithms

(SOAs) are among the three most common types of AI strategies which are used in wind turbine systems.

ANN has several advantages: it is very versatile and can produce high accuracy with fault tolerances, it is self-organizing and direct, easy to implement computation, making them one of the best tools for predicting wind speed, power, and wind density problems compared to SVM; However; SVMs produce excellent results in defect recognition and identification applications. SVMs perform well in some other cases having high accuracy in comparison with ANNs for prediction activities; however, the performance of the SVM, particularly in such domains, also necessitates further investigation and study.

Swarm Intelligence Algorithms (SIAs) are now becoming an area of utmost importance as they are finding application in wind turbine optimization by obtaining collectively intelligent behaviors from nature. It is a trend today that numerous engineers, across all the continents, rely on AI and non-linear controllers to improve wind turbine efficiency. To enhance the practicality of wind-related meteorological predictions, the National Center for Atmospheric Research (NCAR) has put AI into its weather forecast model.

E) AI in geothermal energy

Geothermal energy, although not among natural resources on Earth, has been plenty effective enough for heating small spaces as well as providing natural heat sources for everyday activities like bathing, cooking and washing throughout the centuries-an ancient energy-promising source. By the time of the 20th century, it has evolved to become one of the most reliable and sustainable power sources, due to being commonly accepted by many as a “clean technology” provided by the earth. Yet almost all the large and very old geothermal power plants were built at the peak of the previous “energy boom,” consequently producing an insatiable, continuous approach toward extraction and problems of all kinds. Due to frustrating geological conditions, the financing, and the innovation that is even more as a limitation towards geothermal, RE-based technology, geothermal technology has still been slowest among all these technologies spread out. Experts have consistently emphasized the need to develop techniques leading to a lower uncertain link between geothermal resources, which will help minimize project costs and risks.

However, recent advances in artificial intelligence (AI) and renewable energy (RE) open up opportunities for investment in the exploitation of geothermal energy. Present research employs these technologies almost exclusively towards whole areas, not delving into the potential of integrating machine learning and AI models. AI offers the prospect of tackling problematic issues of geothermal exploration. Initially, AI found use in fairway analyses of regional geothermal evaluations, involving both shallow and deep data. Machine learning techniques are optimised toward replicating human judgments, thereby improving accuracy and efficiency of the exploration process (Dietterich, 2017, 3-24).

A unique trend within thermal research particularly applicable to remote reconnaissance is the use of thermal infrared radiation on Synthetic Aperture Radar (SAR) systems to map prospective geothermal areas. Furthermore, there is a spectrometer for the detection and analysis of mineralogical indicators for geothermal sources, and some researchers even use portable spectrometers to analyse drill core samples. Furthermore, scientists involved in research have already utilized AI-based fuzzy logic algorithms to specify geothermal power quantities via area-scale estimates.

5 Challenges and Solutions

Other forms of renewable energy (RE) are beneficial in their direct use, but present quite a few challenges. One of the major disadvantages concerns the cyclicity of generation essentially because of the identified seasons. Climate-dependency is another feature of most renewable energy sources, instead of ever-increasingly advanced designs, planning, and optimization. Thus, the latter activity becomes the most important to extract maximum economic and technical energies, whereas it also requires opportunities to protect the environment and the social development. Favourably, both computing hardware and software improvements open up fresh possibilities to well-researched activities in terms of optimization issues, ensuring improved computational resources in the context of renewable and sustainable energy.

1. Data acquisition and auditing

Due emphasis becomes actually put on the availability of quality information as an issue that affects the accuracy and likelihood of different industries making substantial developments in artificial Intelligence models or deep learning parameters. By far, the biggest hurdle in this respect is probably the most devastating, and preventive maintenance focused on such a system as the one solar power. This area is characterized by the application of data-driven strategies but at times becomes a barrier due to the huge need for data and hardly available reliable data, particularly in early applications. The measurement always comes with the interference of mechanical components; thus, it is important to analyze the data to detect and control more noise along with multivariate information. It is also very important to be aware of the hazards associated with noisy data and how they affect the performance of the prediction model. Regularly, the bookkeeping and testing are important to ensure that the algorithms keep on running appropriately, and over time, they must have learned the appropriate patterns (Hosseini et al., 2024, 129987).

2. Key variable selection of parameter tuning in RE systems

Definition of key variables in Predictive Maintenance is a prominent step for application in permanent RE technology management as it will engage knowing which important characteristics or factors that affect the results of a model with the objective to result oriented applications are. This tough exercise happens either manually or automatically through a planned supervised expert model which has to consider technical understanding of the domain, different possible reasons for failure, and possible data collection methods. Awareness of the subject matter approaches intermediate in expert or fuzzy systems, with full utilization of neural networks possible with very little depth of understanding with regard to the failure processes. It is, however, much complicated if it is not done well. If not managed favorably, any such forecasting can very likely culminate in power black-outs or constrictive reduction in renewables' output. In fact, unexpected events like pandemics, natural calamities, and emergencies further make it complex for AI prediction systems to generate ultimate problems in making RE systems trustworthy (Kumar et al., 2023, 525).

3. Modeling of various faults simultaneously

Modeling multiple failures at one time, almost by definition, requires using huge sets of data, which in return puts potentially large demands on processing capabilities and potential slows down real-time operations. Such performance operations can manifest in the context of prediction of Renewable Energy (RE) systems when AI-based algorithms untangle the various facets of uncertainty. For instance, vital importance here may lie in the unreliable aspects in RE generation systems. Such unpredictable factors have real-life implications of randomness in generation or system tunings, sourced mainly from the randomness between source-grid-load storage, including dispatch differences impeding or retarding renewable energy production, transmission, and distribution to certain areas. This complexity in renewable energy systems presents monumental challenges for designing of AI forecasting algorithms. However, these related issues serve as an impediment to properly effective results because this all can find viable solutions by introducing a more efficient platform through which the utilization and deployment of AI learning methodologies were integrated.

4. Stability and generalization in predictive modeling

Findings are comprised of a lack of physical data in the system, resulting in some kind of trust failure with the trustworthiness of findings. Thus, intuition can sometimes be rendered useless as data simply doesn't exist. So, one needs to build such models that would be able to discern and react to new sorts of mistakes. The hybrid prospect of today's smart control systems can open up golden opportunities to explore with AI models; nevertheless, without the proper control and modeling technology in place to drive the formation of new renewable energy (RE) networks effectively, it discourages the formation of reliable models. Therefore, it is important that today's controls be enhanced and updated to empower effective modeling and growth for energy-related designs. Solving it could necessitate a search into intelligent AI models and extremely sophisticated algorithms that would make possible a seamless talk between what is present and what could be put up in the future for large scale establishment of renewable energy systems (Ahmad et al, 2024, 718-729).

5. Security and protection against data breaches

In A.I., decision-making and applications, in enormous volume of sophisticated data that may be personal in nature, make them susceptible to major concerns like data breach and identity theft. There are many areas where machine learning applications in smart grid and energy systems have more problems in the face of adversarial attack and security problems than predictive maintenance models. Many predictive maintenance strategies in energy systems also utilize deep learning, cloud computing, and IoT sensors, which, in turn, are vulnerable to cyberattacks and security threats. In consequence, the absence of comprehensive security arrangements becomes one of the significant limitations to the successful deployments in AI in renewable energy. A possible answer to this would be developing strengthened security procedures and technologies that could prevent any future data breach while still allowing the AI systems to develop (Adebimpe Bolatito Ige, 2024, 2978 - 2995).

6. Performance and explainability issues

Operationalization is one of the terms commonly employed within organizational psychology to discuss how managers might determine the degree to which goals or objectives are being achieved. There's always been fiery debate as to whether organizations can actually achieve this, and typically it dovetails with the goal setting, organizational design, and even performance appraisal literature within the majority of organizations. BEINGS processing a variety of disciplinary ventures aims to improve this very individual contribution within organizations in terms of goal setting. Employers can thus gauge the performance levels of their employers in translating a goal or target into a living operational schedule by looking for evidence as to whether or not their employees can define goals expressed in these precision terms. Is it possible to operationalize any goals if, also, its counterpart is refused same? Therein could be considered how research complications become manifested to mean that goal-related outcomes may be construed in the perspective of human capital. It is commonly used theory on the relationship between metrics and meaning-making and how they facilitate respective literatures in two disciplines, BEINGS, and associated programs (Binyamin et al., 2024, 101288).

It is a very technical issue to achieve the balance of what to be decided from what to be predicted in predictive maintenance for energy systems. The deep learning-based strategies, which have to enhance the analytical performance of these networks, while the network remains comprehensible, should be investigated greatly to tackle the challenge.

7. Energy storage and grid integration issues

The necessity to store the energy needed for the future occasional nature of renewable power systems is the admittance to operators of renewables into the larger electric system infrastructure. But there are a range of difficult challenges, starting with the high costs of power storage devices, limited energy density, power density, and the lifetimes of such storage technologies. The advanced devices, including AI, artificial intelligence, image processing, and especially characterization, are shedding light on energy storage at the atomic and molecular level. It could be enhanced to develop next-generation energy storage devices as it has a higher charge density and longer lifespan, as the disintegration from repeated destruction-charge sequences was diminished (Cali et al., 2022, 1841–1852).

Two main challenges also face hydro technology: the safe storage of energy and seamless grid links. Through AI and ML one can develop generators to predict such generative patterns or even brokers like

ChatGPT can guide to predict where the energy is coming from, how it is being produced, and who will be using it. Analysing historical data can be helpful in determining when periods of peak electricity consumption and low hydropower generation might come about in the future, hence helping resource planning and optimization of hydropower plants. Such problems might be solved by creating appropriate mechanisms for retaining electricity, like high-head pumped hydro storage or improved battery systems. Such storage would enable utility of excess energy generated during abundant flow periods, by releasing it when supply dips and load becomes high thereby conferring reliability and viability to hydropower. Under this strategy, consumers can enjoy a continuous, stable energy supply (Kelvin et al., 2024, 2082-2099).

6 Conclusion

This research article demonstrates comprehensive details regarding applied research and undeniable field growth for AI-based algorithms within the developing technology which solves RE systems' minor problems. This research studies specific case studies together with new experimental findings about single and hybrid renewable power systems by focusing on solar power and PV technology and microgrid energy efficiency and wind and geothermal sources. In solar energy, AI simulation approaches provide efficient alternatives to traditional modelling by handling complicated multivariable challenges with minimal computing effort. AI is making a significant impact on PV technology, especially as it analyses vast information on the solar cell materials and performance.

The article can be further developed with AI used for energy storage work in microgrids. Machine learning is part of AI technology, which is designed to predict and monitor wind turbines. AI has another application in mapping and optimizing fairways and geothermal plays by using both surface and subsurface data for analysis. This study discussed the application of artificial intelligence in modeling renewable energy systems for simulation, control, decision making, and optimization.

Recent and future research, prospective problems, and future trends discuss in regional suitability analysis for AI application in real-estate applications. Creative and hybrid AI approaches would address considerable advances in renewable energy technologies, even contributing to the global wealth. Likely, the future study project will focus on field-specific data to better the AI implementation in RE systems.

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