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E-BREEZE

ZEPRA

IN ASSOCIATION WITH
GREEN ENERGY GUARDIANS CLUB

INSTITUTION'S INNOVATION COUNCIL
(Ministry of Education Initiative)
BAJAJ INSTITUTE OF TECHNOLOGY, WARDHA

DEPARTMENT OF
ELECTRICAL AND ELECTRONICS ENGINEERING
EGS PILLAY ENGINEERING COLLEGE (AUTONOMOUS)
NAGAPATTINAM

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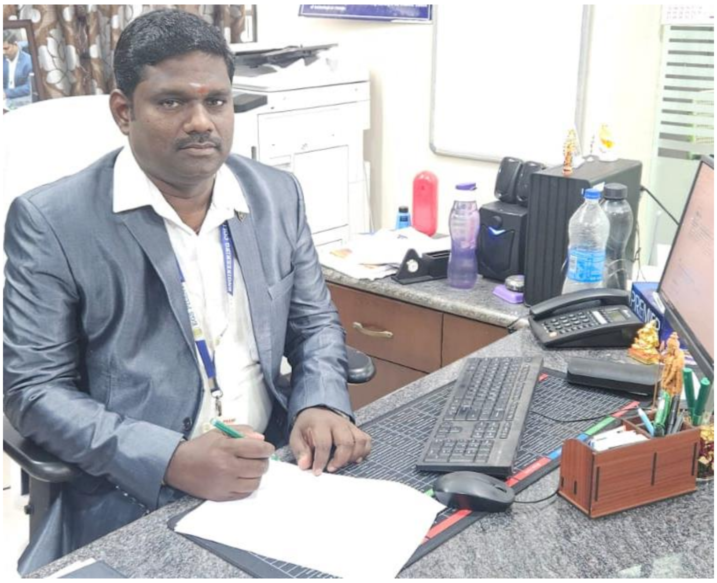
MESSAGE FROM JOINT SECRETARY

SHRI G. SHANKAR GANESH

JOINT SECRETARY - EGS PILLAY GROUP OF INSTITUTIONS

"It gives me immense pride to acknowledge the EEE Department's initiative in organizing the symposium, **E^2 CALONICS'25,** with a special edition magazine to mark this significant event. Such platforms are essential for fostering innovation, allowing our future engineers to demonstrate their skills and leadership potential. I commend the efforts of both the faculty and students, and I am confident that this symposium will provide an enriching experience, contributing to the overall growth and development of all participants. Wishing the entire team every success as they continue to achieve excellence."

MESSAGE FROM PRINCIPAL



DR. M. CHINNADURAI

PRINCIPAL - EGSPEC

Warm greetings to all! It is with great pleasure that I acknowledge the EEE Department of our college for organizing the international-level symposium, **E^2 CALONICS'25**. Under the visionary leadership of our Secretary, Shri S. Senthilkumar, and the dynamic guidance of our Joint Secretary, Shri S. Sankar Ganesh, our institution continues to advance with confidence, clarity, and a competitive Their foresight and decisive leadership have played a pivotal and growth of our college.

This symposium is a commendable initiative aimed at exposing students to the latest advancements in the field of Electrical and Electronics Engineering. It also offers a valuable platform for our students to showcase their innate talents. I deeply appreciate the dedication, hard work, and tireless efforts of the faculty and students who have come together to make this event possible. I extend my congratulations to all involved and wish **E2 CALONICS'25** great success.

MESSAGE FROM HOD

DR.P.J. SURESH BABU M.E., Ph.D.,

HOD/ EEE

"I want to congratulate the students of the EEE Department for their hard work in successfully organizing the international level symposium. It's a great achievement, and your efforts are truly appreciated. I also want to recognize the students for the release of the departmental magazine, '**E-Breeze' 25**, which shows your creativity and teamwork. Finally, I wish the members of **ZEPRA**.

All the best for a successful and bright future."

MESSAGE FROM AHOD

Dr.S.SIVAMANI M.E., Ph. D.,

ASSISTANT HOD/ EEE

“I Am Glad our department will be organizing **the International Level Technical Symposium, E2 Calonics' 25, on 10th October 2025.** Thisevent will bring together young tech enthusiasts from around the worldto discuss innovative concepts in humanizing technology. With scienceevolving rapidly, it is crucial to stay updated and adopt aninterdisciplinary approach. To enhance employability and ensure asuccessful future, students should focus on multi-skilled, applicationorientededucation. The symposium will serve as an excellent platformfor sharing ideas, and the slogan “Think and Link; Link and Think”emphasizes the importance of interdisciplinary research in advancing humanity.I congratulate all participants, paper presenters faculty members, and everyone involved in organizing this event**. I wish E2 Calonics' 25 great success."**

VISION AND MISSION OF THE INSTITUTION

VISION OF THE INSTITUTE

Envisioned to transform our institution into a "Global Centre of Academic Excellence"

MISSION OF THE INSTITUTE

1. To provide world class education to the students and to bring out their inherent talents

2. To establish state-of- the-art facilities and resources required to achieve excellence in teaching-learning, and supplementary processes

3. To recruit competent faculty and staff and to provide opportunity to upgrade their knowledge and skills

4. To have regular interaction with the Industries in the area of R&D, and offer consultancy, training and testing services

5. To establish centers of excellence in the emerging areas of research

6. To offer continuing education, and non-formal vocational education programmes that are beneficial to the society

VISION AND MISSION OF THE DEPARTMENT

VISION OF THE DEPARTMENT:

The department is envisioned to produce globally competent electrical and electronics engineers

MISSION OF THE DEPARTMENT:

M1: To impart the contemporary knowledge in the field of electrical and electronics engineering with high human values

M2: To offer state-of-the-art facilities for conducive learning and conducting research

M3: To prepare the students for professional career and higher education by imparting self-learning and interpersonal skills

PROGRAM EDUCATIONAL OBJECTIVES (PEOS):

B.E – Electrical and Electronics Engineering programme graduates will be able

PEO 1

Graduates will excel as engineering professionals and leaders in electrical engineering or becoming an entrepreneur or pursuing higher education.

PEO 2

Graduates will demonstrate core competence to adapt themselves to the constantly evolving technologies and stay in line with industry advancements.

PEO 3

Graduates will collaborate in multidisciplinary field both as individual and as a team member with a strong sense of professionalism and ethics

Program Specific Outcomes (PSOs):

After successful completion of the programme, Graduates will be able to

PSO 1

Design, test and analyse electrical machines and utility systems

PSO 2

Design, develop and test analog and digital electronic circuits and systems

PROGRAM OUTCOMES(POs)

PO1: Engineering Knowledge: Apply knowledge of mathematics, natural science, computing, engineering fundamentals and an engineering specialization as specified in WK1 to WK4 respectively to develop to the solution of complex engineering problems.

PO2: Problem Analysis: Identify, formulate, review research literature and analyze complex engineering problems reaching substantiated conclusions with consideration for sustainable development. (WK1 to WK4)

PO3: Design/Development of Solutions: Design creative solutions for complex engineering problems and design/develop systems/components/processes to meet identified needs with consideration for the public health and safety, whole-life cost, net zero carbon, culture, society and environment as required. (WK5)

PO4: Conduct Investigations of Complex Problems: Conduct investigations of complex engineering problems using research-based knowledge including design of experiments, modelling, analysis & interpretation of data to provide valid conclusions. (WK8).

PO5: Engineering Tool Usage: Create, select and apply appropriate techniques, resources and modern engineering & IT tools, including prediction and modelling recognizing their limitations to solve complex engineering problems. (WK2 and WK6)

PO6: The Engineer and The World: Analyze and evaluate societal and environmental aspects while solving complex engineering problems for its impact on sustainability with reference to economy, health, safety, legal framework, culture and environment. (WK1, WK5, and WK7).

PO7: Ethics: Apply ethical principles and commit to professional ethics, human values, diversity and inclusion; adhere to national & international laws. (WK9)

PO8: Individual and Collaborative Team work: effectively as an individual, and as a member or leader in diverse/multi-disciplinary teams.

PO9: Communication: Communicate effectively and inclusively within the engineering community and society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations considering cultural, language, and learning differences

PO10: Project Management and Finance: Apply knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, and to manage projects and in multidisciplinary environments.

PO11: Life-Long Learning: Recognize the need for, and have the preparation and ability for i) independent and life-long learning ii) adaptability to new and emerging technologies and iii) critical thinking in the broadest context of technological change. (WK8)

IOT-INTEGRATED SMART ENERGY MANAGEMENT SYSTEM WITH ENHANCED ANN CONTROLLER FOR SMALL-SCALE MICROGRID

Alex Mariyaraj & Suresh Padmanabhan Thankappan

ABSTRACT

This research paper focuses on an intelligent energy management system (EMS) designed and deployed for small-scale microgrid systems. Due to the scarcity of fossil fuels and the occurrence of economic crises, this system is the predominant solution for remote communities. Such systems tend to employ renewable energy sources, particularly in hybrid models, to minimize fuel costs and promote environmental sustainability. However, in small-scale microgrids, a significant challenge lies in maximizing power utilization amidst rapid variations in ecological conditions in renewable energy resources, ensuring energy balance during peak demand, and preventing wastage during low demand condition. To address these issues, this research focuses on two main areas. Firstly, the implementation of the GWO-tuned feed-forward neural network MPPT algorithm in both solar and wind energy conversion systems. This control algorithm demonstrates superior performance compared to existing controllers by efficiently tracking the maximum power point (MPP) value and rapidly utilizing the available power. Secondly, IoT-based energy monitoring system is implemented in small-scale microgrid systems to track the real time of data from sources like wind, solar, and batteries. Furthermore, intelligent rule-based strategies are employed to enhance the control ENGINEERING Tion of EMS and ensure stability within the microgrid. This system effectively manages microgrid demand and prevents power wastage. In this specificnesses, the battery storage unit is a key component, but challenges arise when there are sudden load and power generation fluctuations, leading to disruptions in control mechanisms. To address this, a GWO-tuned ANN controller is integrated into the voltage control loop of the battery controller unit, effectively correcting DC bus voltage fluctuations and maintaining stability.

INTRODUCTION

The rapid expansion of industries in modern civilization and excessive use of non-conventional energy sources lead to the energy crisis that suspiciously affects rural communities and also impacts the environment [1, 2]. So, the developing countries are deciding to generate the power through renewable energy sources, in addition to creating the new distribution system for eco-friendly, minimize the operating cost, reduce the power loss, supply continuous power in rural areas and reduce the tariff to consumers [3–5]. The above-mentioned constraints are suitable for microgrid (MG) systems. It consists of renewable energy sources like PV and wind with energy storage systems connected on conventional grid [6–11] as illustrated in Fig. 1. The majority of benefits are available in microgrid even though some of the technical issues present. The maximum energy utilization in hybrid RES is very difficult because the energy sources are intermittent in nature and the second issue is power balance between sources and sudden raising consumers load [9], due to improper scheduling of the load for non-availability of hybrid energy resource. Furthermore, ineffective control mechanism for battery management system causes cycle aging, temperature sensitivity and an imbalance in the state of charge (SOC), resulting in an unstable DC bus voltage [12–15]. To tackle the mentioned concerns, a proposed intelligent energy management system aims to enhance the performance of small-scale microgrid systems. The energy management primary work is to optimize the use of energy from hybrid resources and minimize energy wastage. [16], second with the absence of hybrid source the battery energy storage system effectively works to maintain power balance to make system reliable, third an islanded mode hybrid power generation-based proper load scheduling action is taken to regulate the voltage and frequency in standard level, and finally, the entire work is smartly monitoring and cordially controlling the microgrid system to make it reliable, stable and economic [17–22]. In a small-scale microgrid system, a hybrid power source is required to ensure sustainability. Such sources necessitate an efficient controller for optimal utilization of power. In off-grid mode, it is essential to maintain a balance in energy supply by utilizing battery backup with the assistance of advanced controllers for charging and discharging during rapid variations in load and input power. Furthermore, real-time monitoring and a smart management system are crucial for ensuring the reliability and stability of the system. From the above discussion work, the control measures are found based on the literature review step by step. In the domain of hybrid energy systems, the primary emphasis of researchers is on enhancing energy efficiency and reducing greenhouse gas emissions, specifically in on-grid, off-grid and grid integration scenarios [23–27]. Some scholars delve into the analysis of modeling and sizing hybrid systems [28–30]. One group of authors implemented a hybrid system to provide battery backup for ensuring power reliability to end-users [31, 32]. Furthermore, authors [33] offer a detailed review of the design, modeling and optimization techniques related to hybrid systems. Recent articles indicate that hybrid systems are well-matched for microgrid applications due to their improved power supply reliability, efficient utilization of diverse resources, energy self-sufficiency, and reduced environmental impact. However, certain limitations are also noted, including dependency on weather conditions, technical challenges such as grid integration and maintaining voltage and frequency regulation in off-grid conditions, as well as the increased complexity in design, control topologies, and maintenance when more renewable energy sources are installed. Based on the aforementioned observation, I deduce that effective control techniques are imperative in microgrid hybrid solar–wind systems with battery integration. Furthermore, a detailed examination of the solar energy conversion system, wind conversion system, and battery storage system control algorithms will be conducted sequentially. Practically, solar and wind energy conversion efficiency is low such as 17–21% and 20–40%, respectively. The observation must be made that the level of effectiveness in converting energy is of moderate quality, so to enhance the efficiency of converting renewable energy, it is crucial to employ a proficient control algorithm. The solar energy conversion system employs traditional maximum power point tracking (MPPT) algorithms such as hill climbing (HC) [34], incremental conductance (IC) [36, 37], modified incremental conductance method (MICM)[38, 39], perturb and observe (P&O) [40] and finally improved perturb and observe method (IPSO) [41, 42] within its controller and it facilitates the effective tracing of the maximum power point, leading to an overall improvement in system performance. These controlled algorithms are simple, robustness and effectively track MPP in constant ecological condition, but rapid variation of these controller tracking abilities is very less and produced the oscillated reference signal

ENGINEERING FACTS

5G and early 6G networks are enabling ultra-fast IoTdevices with millisecond latency.

VLSI DESIGN

Faculty book publication – Dr.P.J.Suresh Babu & Dr.S.Sivamani

ABSTRACT

The field of VLSI (Very Large-Scale Integration) Design plays a pivotal role in shaping the modern digital era, enabling the integration of millions of transistors on a single chip to achieve high performance, low power consumption, and compact hardware solutions

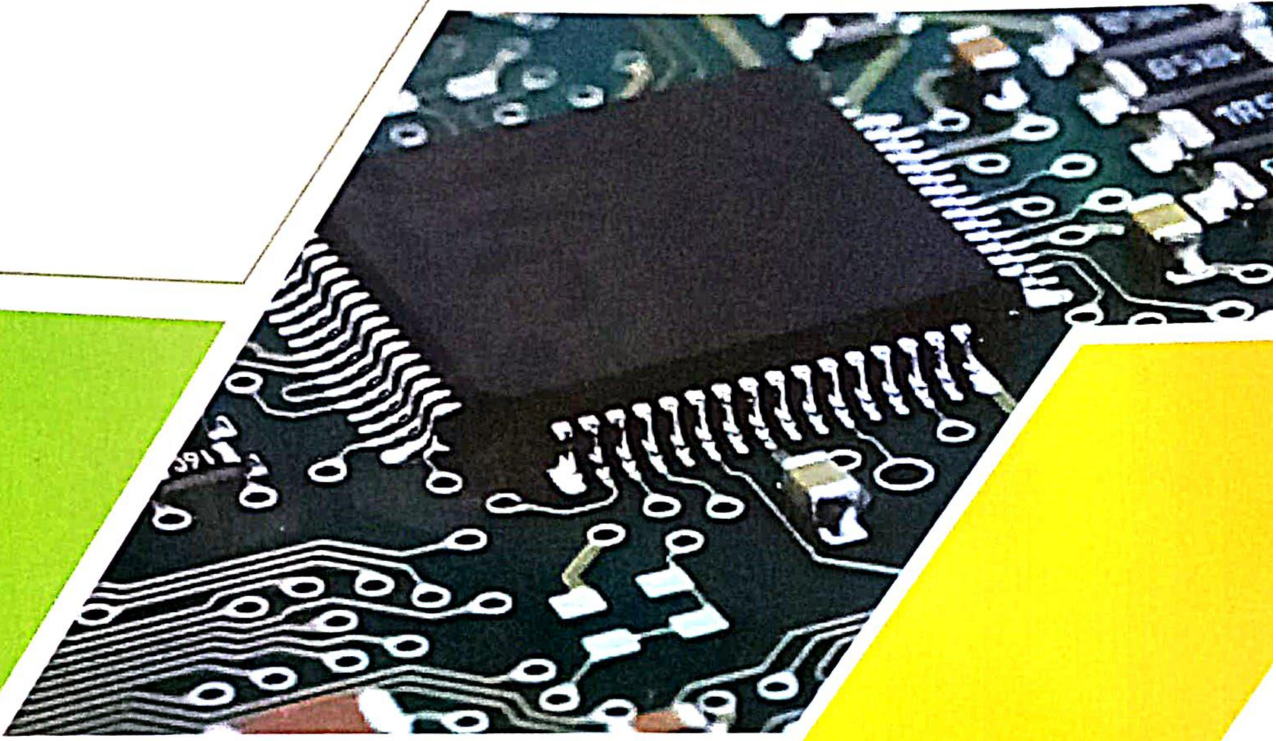
This book provides a comprehensive exploration of the principles, methodologies, and advancements in VLSI design, bridging the gap between theory and real-world semiconductor applications.

It covers essential topics such as digital and analog circuit design, CMOS technology, system-on-chip (SoC) architectures, low-power techniques, and design automation tools (EDA).

With the growing demand for intelligent and energy-efficient systems, VLSI design continues to drive innovation in areas like AI hardware, IoT devices, embedded systems, and next-generation communication technologies.

This book aims to serve as a foundational guide for students, researchers, and professionals, fostering a deeper understanding of how miniature circuits power today's smart and sustainable world.

VLSI Design



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SOLVING OPTIMAL POWER FLOW PROBLEM IN HYBRID RENEWABLE ENERGY SYSTEMS THROUGH HYBRID OPTIMIZATION ALGORITHM

P. J. Suresh Babu, S. P. Mangaiyarkarasi, R. Gandhi Raj, **S. Senthilkumar**

ABSTRACT

The growing global emphasis on sustainability has accelerated the transition from fossil fuels to renewable energy sources. Hybrid renewable energy systems, integrating wind and solar energy, have emerged as efficient alternatives for cleaner energy generation. However, managing Optimal Power Flow (OPF) within these systems remains a critical challenge due to the inherent uncertainties in renewable energy resources and the nonlinear nature of OPF problems. This study proposes a novel hybrid optimization approach—hybrid spotted hyena optimization algorithm—that integrates spotted hyena optimization with a quadratic approximation operator and grasshopper optimization to improve convergence speed, solution quality, and resilience to uncertainties. Uncertainties in wind and solar generation are modeled using Weibull and log-normal probability distributions, respectively, incorporated through Monte Carlo simulations. The algorithm is tested on the modified IEEE-30 bus system. Compared to conventional methods like PSO, GA, and GWO, the proposed model achieved a minimum fuel cost of 658.98 USD/hr, reduced power loss to 3.684 MW, and minimized voltage deviation to 0.0756 p.u., demonstrating significant improvements in efficiency and reliability. These results confirm the broader applicability of the model in achieving sustainable and cost-effective power management in renewable-driven smart grids. *Keywords Hybrid energy systems _ Optimal power flow _ Spotted hyena optimization algorithm _ Quadratic approximation operator _ Grasshopper optimization _ Emissions reduction _ Sustainable energy management*

INTRODUCTION

The global energy demands have increased over the last few decades due to industrial expansion, population growth, and technological advancements. The necessity of finding alternatives to fossil fuel-based sources has always been a high priority among researchers. The environmental and economic challenges forced the world to find an alternate non-renewable energy source. Harnessing energy from wind power and solar (Senthilkumar et al. 2023) resources is considered a primary choice of alternatives due to its availability and low environmental impact. However, wind and solar intermittent natures possess challenges in power generation while providing a reliable and consistent electricity supply. Thus, HRES are developed that combine wind and solar energy systems (Roy et al. 2022; Hassan et al. 2023; Babatunde et al. 2020). Numerous efforts are made to improve the performance of HRES using advanced computational technologies. The major issue in HRES is the OPF problem, which defines the optimal operation of power systems (Ullah et al. 2022; Malar et al. 2020). By determining optimal parameters such as voltage levels and generator outputs, OPF effectively minimizes the operating cost and satisfies the operational constraints. To handle the OPF problem in an HRES, an optimization algorithm can be used so that enhanced reliability, minimized cost, and maximized efficiency can be attained. Optimization algorithms fine-tune the system by selecting optimal parameters so that maximum power generation and distribution can be obtained with minimized operating costs (Nappu et al. 2023; Papazoglou and Biskas 2023). Resources can be effectively maintained so that the grid reliability can be improved. However, conventional optimization algorithm that are used for the OPF problem often face issues in finding optimal solutions effectively due to the complex hybrid power system characteristics. The quadratic nature of the OPF problem brings challenges to conventional optimization algorithms. Thus, it is essential to find an optimal solution for the OPF problem through hybrid optimization algorithms, which perform better than conventional optimization algorithms. To attain this, a hybrid optimization model is proposed in this research work. The major research objective is to develop a novel hybrid optimization model that should handle the quadratic nature of the OPF problem and provide optimal solutions to improve the overall efficiency of the HRES. By attempting the OPF optimization problem with the proposed advanced computational method, this research aims to advance sustainable energy infrastructure and promote environmental responsibility. This research makes the following significant contributions to solving the OPF problem in HRES: • A novel hybrid optimization model is presented to solve OPF problem by combining spotted hyena optimization, the quadratic approximation operator, and grasshopper optimization. Each element of the hybrid algorithm is explained in terms of enhancing exploration and exploitation capabilities, thereby improving convergence speed and solution quality. Spotted hyena optimization is selected for its exploration efficiency, quadratic approximation operator for handling nonlinearities, and grasshopper optimization for its exploitation strengths. This hybrid approach is aimed at addressing the complexities inherent in HRES, overcoming the limitations of single optimization techniques in handling uncertainties in the OPF problem. • The performance evaluation of the proposed hybrid optimization is presented by employing the IEEE-30 bus test system. The experimental analysis considered various performance metrics such as fuel cost, total power loss, voltage deviation, and convergence metrics. By using a real-world test system, the study ensures the relevance and applicability of its findings to practical scenarios. • Presented a detailed comparative analysis against existing optimization techniques to validate the proposed model performance. The methodology employed for experimental evaluation underscores the research's commitment to robustness and reliability in assessing the proposed optimization algorithm. The rest of the discussion in the article are summarized as follows. Discussions based on existing research works is presented in Sect. 2. The proposed hybrid optimization algorithm and uncertainty models are presented in Sect. 3. Experimental results are presented in Sect. 4. The last section presents the conclusion of the research work. 2 Literature Review This section presents a summary of recent research work that considered the OPF problem as its main objective. Single and hybrid optimization algorithms that are used for the OPF problem are considered for analysis, and the summary is presented in this section. To optimize the HRES performance and to handle the OPF problem, a hybrid model is introduced in Praveen Kumar et al. (2021) that includes PLSANN/RNN techniques. The evaluation of the DC/DC converter in the HRES is done through the proposed model and manages the OPF. Additionally, for real power optimization, the lighting search algorithm (LSA) is incorporated, which effectively optimizes the power requirements. The RNN employed in the presented model handles the optimal reactive power requirements. Thus, by managing the active and reactive power requirements and continuously evaluating the converter line, the presented model attains better performance than traditional GA and PSO techniques. The hybrid technique reported in Vijayaragavan and Darly (2019) manages the OPF problem in grid-connected

HRES. The presented model includes the cuttlefish algorithm and the ANN model to optimize the control signals. The optimal solutions provide precise control signals, and the ANN model reduces the implementation time. The presented model enhances power system performance and minimizes the error by controlling the power converters. Experimental results demonstrate the better performance of the presented model over traditional approaches. The hybrid model presented in Riaz et al. (2021) for the OPF problem combines PSO and GWO algorithms to provide global search features. The presented model initially evaluates the wind turbine and solar PV module output power using a probability distribution on Monte Carlo simulations. Experimental results of the minimized generation cost compared to existing metaheuristic optimization algorithms. The hybrid model presented in Suresh et al. (2021) combines TFW and BRO algorithms to solve the OPF problem in HRES. The presented model aimed to reduce control power flow and cost using the optimal solution of the TFW and BRO algorithms. The control parameters for power flow variation are optimized by the hybrid optimization model so that better performance is obtained in HRES compared to existing methods. To address the OPF challenges in HRES, various metaheuristic algorithms are used in Sulaiman and Mustaffa (2021). Black widow optimization, gravitational search optimization, grey wolf optimization, particle swarm optimization, barnacles mating optimization, grasshopper optimization, moth flame optimization, and ant lion optimization are included for analysis. The comparative analysis results identify that the performance of barnacles mating optimization is better than the other optimization algorithm in solving OPF problems. Using the vulture optimization algorithm, the optimal solution for OPF is obtained in Srikanth et al. (2021). The presented mode combines the optimization algorithm with random forest to minimize the power loss and harmonic distortions and provide better voltage stabilization. The optimal parameters, like load current, gain parameters, voltage sources, and link voltage are obtained through the optimization algorithm. The optimal control signal is predicted through random forest with minimum error, thereby the presented model attained better performance over traditional optimization algorithms like GSA and random forest algorithms. A detailed comparative analysis of optimization algorithms in solving the OPF problem of HRES is presented in Sundaram (2022). The presented multi-objective predicts the required power through probability distribution like lognormal, Weibull, and Gumble. Further, the solutions are obtained through optimization algorithms, and the results depict the equilibrium optimizer's better performance in terms of faster convergence over other optimization algorithms. In order to enhance the solution diversity in solving the OPF problem of HRES, chaos game optimization is combined with an artificial ecosystem-based optimization algorithm in Mohamed (2023). The presented model aimed to minimize the transmission losses, fuel costs, and voltage deviations through the obtained optimal solution. Experimental results demonstrate that the presented model performances are better than traditional CGO and other optimization algorithms. Using bird swarm optimization, the OPF problem is addressed in Ahmad et al. (2021) and attains stable and accurate solutions based on the optimal outputs of the optimization algorithm. The experimentations include stochastic electricity output of HRES and utility load demand and validate the minimum generation cost of the presented model. The hybrid optimization algorithm presented in Dsouza et al. (2023) utilizes improved binary sailfish optimizer (IBSO) and kho = kho optimization with RBNN to attain better efficiency. The power flow is regulated in the first phase of research work using IBSO. Using kho-kho optimization, PI controller parameters are fine-tuned to improve the power quality in the second phase. Finaly, using RBNN, the errors are minimized by predicting the optimal control signals. Experimental results present that higher efficiency of the proposed model over existing techniques. Grey wolf optimization is employed in Khan et al. (2020) to solve the OPF problem in HRES that includes solar, thermal, and wind power generators. Using Weibull and lognormal PDFs, the uncertain power is forecasted. Then the optimal solution is obtained using GWO and attains reduced cost and better convergence than conventional approaches. The multi-objective model presented in Li and Li (2020) to solve the OPF problem utilizes a bicriterion evolution indicator-based evolutionary algorithm to perform parallel computation. The complex cases in the OPF problem are identified through the selection and least absolute shrinkage operator and attain improved computational efficiency over traditional methods. In (Hassan et al. 2024), a hybrid algorithm, AHMRFO, is proposed that combines the artificial hummingbird algorithm (AHA) and manta ray foraging optimization (MRFO) solvers to address a variety of single-objective OPF issues, including generation cost and total emission. By utilizing the superior performance of the MRFO and AHA algorithms in resolving OPF problems, the AHMRFO seeks to increase optimization efficiency. From the above summary, it can be observed that solving the OPF problem could be better when utilizing a hybrid optimization algorithm. However, selecting an appropriate algorithm is essential so that better exploration and exploitation features can be obtained and the problem can be solved efficiently. Thus, to address the OPF problem in HRES (Khan et al. 2024), a novel approach combining the Spotted Hyena Optimization with quadratic approximation operator and grasshopper optimization (SHQAGO) is proposed in this research work. The SHQAGO model would effectively optimize power flow management in HRES and potentially offer improved performance and computational efficiency compared to existing methods. From the above exhaustive literature review, the following research gaps have been identified as presented in Table 1.

ENGINEERING FACTS

***Quantum processors** are reaching 1,000+ qubits, opening a new era of super-fast computing.*

DESIGN AND ANALYSIS OF SOLITARY AC–AC CONVERTER USING REDUCED COMPONENTS FOR EFFICIENT POWER GENERATION SYSTEM

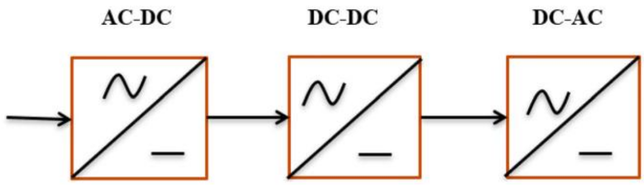
K. Nandakumar, V. Mohan, Faisal Alsaif & S. Senthilkumar

ABSTRACT

Considering different applications that require varied power and voltage conversion levels between AC grids and AC loads, AC–AC power conversion between AC grids has become an inevitable technology of energy management systems. An isolated converter for performing AC-to-AC transmission is proposed with minimal components for reduced losses and enhanced system efficiency. Single-phase direct buck-boost AC to AC converter with minimum components constituted with two dual IGBT control units (IGBT 1–IGBT 4), inductor (Lf), and capacitor (Cf) is proposed in this work. The MATLAB/ Simulink platform is used to provide in-depth analysis of the circuit and components along with the design guidelines, and simulation outcomes of this proposed model. The voltage gains of G = 2.13, power factor of 0.97, and overall efficiency of 98% are achieved in the proposed system with minimum components of 4 switches, 2 conductors, and 1 capacitor and inductor respectively. The obtained results are compared with existing technology to evaluate the proposed system.

INTRODUCTION

AC–AC converters play an important role in industry since they are often used in machine speed control, along with low frequency and variable voltage magnitude. Due to their significance, it has become a current research topic in the evolution of AC-to-AC converters. Commonly, this type of conversion is accomplished using thyristor-based controllers to generate the correct output voltage by refining phase angle1– 5. An AC waveform can be converted to another AC waveform with arbitrary output voltage and frequency settings using a solid-state AC–AC converter. It is possible to realize an AC–AC converter with bidirectional power flow and input currents that are roughly sinusoidal by connecting a PWM rectifier and an inverter to the DC link. The energy storage component shared by both stages, which is either an inductor L for the current DC-link or a capacitor C for the voltage DC-link, then impresses the DC-link quantity. Moreover, the PWM inverter stage has a consistent, AC line-independent input quantity, which leads to a high utilization of the converter's power capacity (Szcześniak et al. 2015). However, the DC-link energy storage element has a comparatively high physical volume, and in the case of a voltage DC-link, there may be a shorter system lifetime if electrolytic capacitors are utilized. Figure 1 shows the types of three-phase AC–AC converters. Figure 1 shows the basic AC–AC conversion steps. However, this type of circuit has numerous problems like system efficiency and harmonic disturbances leading to the establishment of filters in the system. Pulse Width Modulators (PWM) based converters discussed in6– 11 alleviate the disadvantages of thyristor-based AC controllers by providing a means to tackle commutation complications and offering more efficiency. A pulse width modulation technique for conversion was adopted by6, and commutation complications are handled by utilizing the changing cell topology and combined inductors. Further, it is performed by utilizing the Z impedance, which allows protected commutation and a larger value of output voltage. Furthermore, the converters proposed by8– 14 were the revised ones than the devices given by6,7 which are supposed to be free of issues. In8, they use magnetic integration to remove the filter from changing cell AC to AC converters. To achieve high voltage levels, several different changing cell methodologies were proposed9. In addition, Kim et al.12 introduces the usage of changing multilevel AC to AC converter to restore potential differences.



fficiency, Simplified device structure, improved power factor, lower noise, easy device control, and reduced i/p and o/p filter setup when compared to thyristor-based controllers. Among the commonly used three types of PWM AC to AC converters, the resulting voltage along with the frequency of both in-direct and matrix-oriented converters can be adjusted15– 18. Matrix-oriented converters necessitate greater units of semiconductor control, resulting in low efficiency as well as large size and expense. Furthermore, it has severe commutation issues as discussed in19– 22. Whereas the direct type converter is based on one-step power conversion which can vary the required voltage. Since the conversion is done in one stage, with reduced size and economic nature, this type is used for regulating the resulting voltage23. Common direct mode converters evolved through common DC converters by substituting bidirectional control for unidirectional control24– 26. Because of the flap time duration with the end time duration that happens over complimentary control units, all of these topologies have commutation issues. Current and voltage spikes are caused by the flap time duration with end time duration, which destroys semiconductor controls. In3, a series of traditional Z-source-based AC to-AC converters that may step up the fed-in voltage demand and a complicated control technique to solve the commutation concerns were discussed. To address the limitations of the general Z-source AC to AC converter which is studied and analyzed in2– 5 the modified ostensible Z-source AC to AC converter was developed. Single-phase converters were built in27 by substituting the standard PWM converter's bidirectional switches with the linked inductor and the control cell topology. Even though the above-mentioned type eliminates the reverse recovery issues and solves the commutation problem, these mentioned type converters are affected by circulating current components resulting in greater losses, and strain control, which degrades the overall efficiency of the system. As discussed by28, a converter set is designed to overcome to compensate for the imperfection of the type of converters discussed in27. Rotating the magnetic field with the current of connected inductors is minimized by substituting the inductors present in the circuit using a very small inductor. Later29 introduces a 1Φ buck-boost AC to AC conversion by using reduced components. This modified system has a sophisticated swapping technique that necessitates the use of dual capacitor units during dead time and to overcome difficulties. A novel topology of Z-source AC to AC converter was discussed in30– 32 by substituting the components which were proposed by29. This device is made up of four control units and diodes respectively which necessitate the use of dual capacitors, each connected parallel to minimize the inference over input voltage in the circuit. The discussed converters essentially need a high number of active, passive switches, which escalates the area and expense of the converter with the decrease in its overall performance. Figure 2 represents the different types of AC–AC converter. Ahmed et al. 33 Introduces a 1Φ AC to AC converter to correct the grid potential, which requires a large quantity of components. This topology employs six control units, and diodes, supported with each inductor, and capacitor. As described by34– 36, the converter of direct mode can further be used for potential compensation and output power regulation. Many studies are being conducted to improve the tame and adaptability of the converters. In36, for straight AC to AC power conversion, a spurious 2Φ input voltage-based AC voltage generation way with supporting regulation methodology is described37– 39. A 1Φ AC to AC converter with minimum components works as a converter is introduced in this research. Every method of operation uses only one control with the diode of another control unit, reducing circuit losses. The suggested converter has no commutation issues because the input value of the current is constant. Furthermore, even if the complete switches are turned on at the same moment, there is no chance of the input source shooting through. **Proposed AC to AC converter** **Figure** 3 represents the converter model discussed in this study with minimum components constituted with two dual IGBT control units (IGBT 1–IGBT 4), inductor (Lf), and capacitor (Cf). Lo and Co represent the input.

ENGINEERING FACTS

***LED bulbs** are not only energy efficient, but they also **last 25 times longer** than traditional bulbs*

SOLAR PV OPTIMIZATION WITH AI-BASED MPPT

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ABSTRACT:

The increasing global demand for renewable energy has highlighted the need for improved efficiency in photovoltaic (PV) systems. One of the critical challenges in solar energy conversion is maximizing power output under varying environmental conditions. This study presents an AI-based Maximum Power Point Tracking (MPPT) approach to optimize the performance of solar PV systems. Unlike conventional MPPT techniques such as Perturb and Observe (P&O) or Incremental Conductance, the proposed method employs Artificial Intelligence algorithms specifically Machine Learning and Deep Learning models to accurately and dynamically track the maximum power point in real time. Simulations and experimental results demonstrate that the AI based MPPT not only enhances tracking speed and accuracy but also significantly improves energy yield, especially under partial shading and rapidly changing irradiance conditions. The integration of AI into MPPT represents a promising advancement toward smarter and more efficient solar energy systems.

INTRODUCTION:

The global demand for clean and sustainable energy continues to rise, solar photovoltaic (PV) systems have become an essential component of the renewable energy landscape. However, despite their widespread adoption, the efficiency of solar PV systems remains a critical challenge due to varying environmental conditions such as irradiance, temperature, shading, and panel orientation. To address these issues, Maximum Powe

r Point Tracking (MPPT) techniques are employed to ensure that solar panels operate at their optimal power point, thereby maximizing energy harvest.

Traditional MPPT algorithms such as Perturb and Observe (P&O), Incremental Conductance (INC), and Hill Climbing are widely used but often struggle with dynamic and nonlinear operating environments. These methods may lead to slow tracking, oscillations around the maximum power point, or suboptimal performance under rapidly changing conditions.

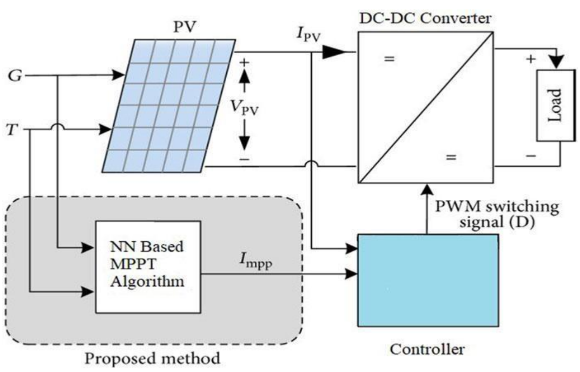
This paper/project explores the application of AI-based MPPT methods in optimizing solar PV performance. By leveraging advanced AI models, the aim is to improve the overall efficiency of solar energy systems, reduce energy losses, and contribute to more reliable and intelligent renewable energy solutions.

AI MODEL DESIGN FOR MPPT:

AI model design for Maximum Power Point Tracking (MPPT) refers to the process of developing and configuring artificial intelligence algorithms—such as neural networks, fuzzy logic systems, or reinforcement learning agents to accurately and efficiently track the maximum power point of a solar photovoltaic (PV) system under varying environmental conditions.

This design involves selecting appropriate input features (e.g., solar irradiance, temperature, voltage, current), determining the model structure (e.g., number of layers in a neural network or rules in a fuzzy logic system), training the model using historical or simulated data, and deploying the model for real-time control of power electronic converters (such as DC-DC converters) in a solar PV system.

The main objective of AI-based MPPT model design is to enhance the adaptability, accuracy, and speed of the MPPT process especially under complex, dynamic conditions like partial shading or fluctuating weather where conventional methods may fail or perform sub optimally.

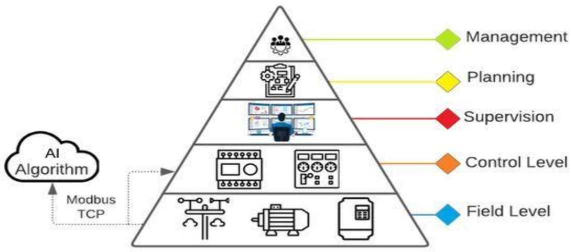


CHALLENGES AND FUTURE TRENDS IN AI-BASED MPPT:

Challenges and Future Trends in AI-Based MPPT revolve around improving the reliability, efficiency, and adaptability of AI algorithms in real-world solar energy systems. One of the key challenges is the need for large and high-quality datasets to train AI models effectively; without sufficient data representing various weather conditions, the models may perform poorly in unseen scenarios. Additionally, the computational complexity of some AI algorithms, such as deep neural networks or reinforcement learning, may hinder their implementation in low-cost or real-time embedded systems with limited processing power. Ensuring real-time responsiveness and robustness under rapidly changing irradiance conditions remains another concern. Moreover, the lack of standardized benchmarks and performance metrics for comparing different AI-based MPPT methods can make it difficult to evaluate and adopt these systems universally. Despite these challenges, future trends in AI-based MPPT are promising. There is growing interest in hybrid models that combine multiple AI techniques (e.g., ANN with fuzzy logic or optimization algorithms) to leverage their individual strengths. The integration of edge computing and lightweight AI models is also expected to enable faster, energy-efficient MPPT control on embedded devices. Furthermore, advances in online learning and adaptive algorithms may allow MPPT systems to continuously learn and optimize in real time without retraining. As renewable energy integration becomes more widespread, AI based MPPT is poised to play a critical role in enhancing the intelligence and efficiency of future solar power systems

REAL TIME ADAPTABILITY OF AI ALGORITHM:

Real-time adaptability of AI algorithms refers to the ability of the algorithm to respond and adjust instantly to changing environmental conditions during operation. In the context of AI-based MPPT (Maximum Power Point Tracking) for solar photovoltaic systems, real-time adaptability is crucial because solar irradiance and temperature can fluctuate rapidly due to cloud movement, shading, or time of day. An AI algorithm with real-time adaptability can analyze incoming data such as voltage, current, irradiance, and temperature in milliseconds and update control signals accordingly to ensure the system operates at or near the maximum power point at all times.



This dynamic responsiveness allows the AI model to outperform traditional static algorithms by reducing power losses, minimizing oscillations, and quickly stabilizing after disturbances. Techniques like online learning, incremental training, or reinforcement learning are often used to enhance real-time adaptability, allowing the model to continue learning and optimizing its behaviour even after deployment. This capability is especially valuable in autonomous energy systems, where continuous performance without manual intervention is essential. Overall, real-time adaptability makes AI algorithms highly suitable for smart energy applications, ensuring efficient energy harvesting an improved system reliability.

EFFICIENCY AND ACCURACY METRICS:

Efficiency and accuracy metrics are essential for evaluating the performance of AI based MPPT (Maximum Power Point Tracking) algorithms in solar photovoltaic systems. These metrics determine how effectively the system is able to track and extract the maximum available power from the solar panel under varying environmental conditions. One of the most critical indicators is tracking efficiency, which measures the ratio of the power extracted by the algorithm to the actual maximum power of the PV panel, typically expressed as a percentage. A high tracking efficiency indicates that the AI algorithm is accurately following the optimal operating point. Another important metric is response time, which refers to how quickly the algorithm can adjust to changes in irradiance or temperature; faster response times are preferred to minimize power loss. Additionally, accuracy metrics such as Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) are used to quantify how closely the predicted power values match the actual values. Low error values indicate a more precise prediction model. Other considerations include steady-state oscillation, which reflects the stability of the output around the maximum power point, and computational efficiency, which measures the speed and resource usage of the AI algorithm in real-time applications. Together, these metrics provide a comprehensive assessment of an AI-based MPPT system's effectiveness, stability, and real-time performance.

CONCLUSION:

The integration of AI-based MPPT (Maximum Power Point Tracking) techniques in solar PV optimization represents a significant advancement in renewable energy technology. Unlike traditional MPPT methods, AI algorithms offer improved adaptability, accuracy, and efficiency in tracking the maximum power point under dynamic and non-linear environmental conditions such as fluctuating sunlight and temperature. Techniques like Artificial Neural Networks, Fuzzy Logic, Genetic Algorithms, and Reinforcement Learning enable intelligent decision-making, faster response times, and reduced energy losses. These models can learn complex patterns, adapt in real-time, and provide stable performance, making them ideal for modern solar energy systems. As solar power continues to play a critical role in sustainable energy generation, the use of AI for MPPT not only enhances system reliability and energy yield but also supports the broader goal of smarter and more autonomous renewable energy management. Continued callability, affordability, and robustness of solar PV systems globally.

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ENGINEERING FACTS

Lightning power → A single bolt of lightning can contain up to 1 billion volts of Electricity

IOT, AUTOMATION AND COMMUNICATION

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ABSTRACT:

The convergence of Internet of Things (IoT), automation, and communication technologies is transforming the way systems operate across industries, from smart homes and healthcare to manufacturing and transportation. IoT enables the interconnection of physical devices that collect and exchange real-time data, creating a foundation for intelligent decision-making. When integrated with automation, these systems can perform tasks with minimal human intervention, enhancing efficiency, accuracy, and scalability. Seamless communication protocols—both wired and wireless—play a crucial role in ensuring reliable data transfer between devices, cloud platforms, and users. This abstract explores the synergy between IoT, automation, and communication, highlighting their combined impact on improving operational performance, enabling predictive maintenance, optimizing resource usage, and paving the way toward fully autonomous systems. As these technologies continue to evolve, they are driving the development of smarter, more connected environments across all sectors.

INTRODUCTION:

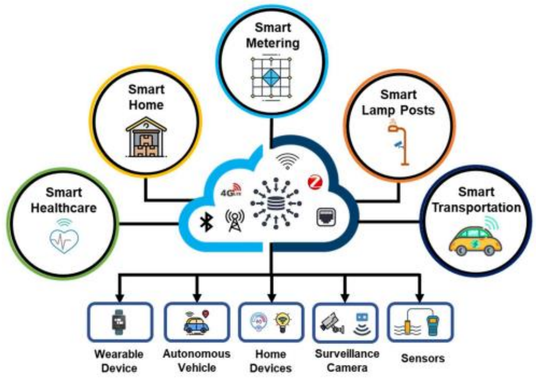
In recent years, the rapid advancement of digital technologies has led to a significant transformation in how devices interact, operate, and make decisions. At the core of this technological shift lies the integration of the Internet of Things (IoT), automation, and communication systems, which together form the foundation of modern smart environments .The Internet of Things (IoT) refers to a network of interconnected physical devices embedded with sensors, software, and other technologies, enabling them to collect and exchange data over the internet. These devices—ranging from simple household appliances to complex industrial machines—serve as the eyes and ears of modern digital ecosystems. Automation, on the other hand, involves the use of technology to perform tasks without human intervention. When coupled with IoT, automation systems can respond dynamically to data, enabling real-time decision-making, predictive maintenance, and adaptive control processes. Effective communication is what links these components together. Reliable data transmission between devices, systems, and users is essential for IoT and automation to ENGINEERING Tion cohesively. This includes both machine-to-machine (M2M) and machine-to-human (M2H) communication, leveraging technologies like Wi-Fi, Bluetooth, Zigbee, 5G, and cloud computing platforms.

The integration of these three domains is revolutionizing sectors such as smart cities, healthcare, agriculture, manufacturing, and transportation, leading to improved efficiency, cost savings, enhanced safety, and better user experiences. This paper explores the interdependence between IoT, automation, and communication, examining their roles, challenges, and future potential in shaping intelligent, connected systems.

IoT Systems:

Internet of Things (IoT) is a paradigm interconnecting different computing devices enabling advanced services based on the existing and emerging technologies. The main purpose of IoT devices is to interact with the physical world and generate data that can then be analysed and used for smart applications. Network connectivity in IoT not only enables remote entities to exchange data but also helps the backend in controlling physical objects out in the field [8- 10]. In general, the operations of IoT systems can be categorized into the following: Data Acquisition: Raw data

collected by the sensors accommodated in the devices till dissemination. Data Transmission Communication of acquired data with the help of connectivity substructure from devices to the backend. Data Analytics on the accumulated data at the backend for example remote server or cloud service etc. Adaptive Judgement Real Time decisions based on the information generated from analysis. The potential of IoT systems can be optimally utilized in large-scale applications like Smart Cities



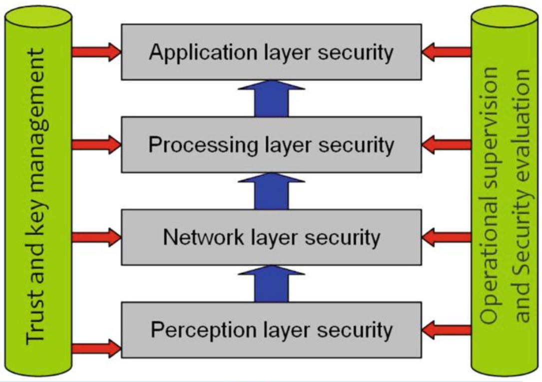
[11],[12] with the goal of improving the quality of life significantly. Smart cities make use of IoT infrastructures for solving issues ranging from traffic congestion to healthcare.

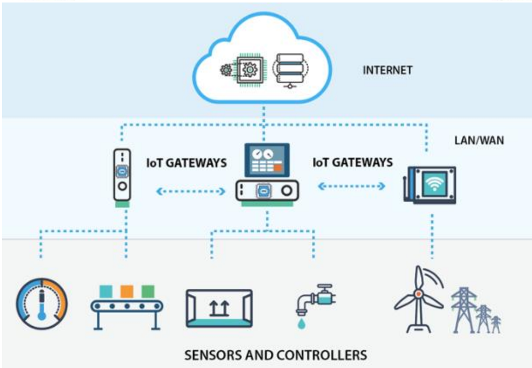
IoT Underlying Technologies:

As mentioned earlier, IoT is supported by various underlying technologies. The most important ones are discussed briefly below for clearer understanding of the enabling technologies important for this work. Big Data for IoT: IoT systems typically gather heterogeneous data from distributed sensors. Though some kinds of sensor data can easily be structured, the overhead, for example of relational databases, needs to be considered. For performance reasons, data may be stored in semi structured or unstructured form. Certain IoT applications even create huge amounts of unstructured data for example applications involving video surveillance. Besides storing data for later analysis, IoT systems often utilize the data gathered for real time decision making. Hence, to handle the stream of incoming data, IoT systems usually employ methods from Big data including preprocessing to reduce data and increase utility, cloud computing to gather sufficient processing power and bandwidth, and advanced machine learning techniques to make models based on the pre-processed data [3],[13]. As the processed data is used for further decisions in an IoT application data integrity is a primarily important for big data security. Data confidentiality and privacy are also quite important as big data involves an enormous amount of data storage and analytics.

IoT Architecture:

IoT architecture entails a structure which provides a high-level overview of processes conducted between all involved parties like end devices, cloud, users etc. There are several approaches that can be followed to design an IoT architecture depending on the requirements of the target application or a certain organization. Developing applications for the IoT could be a challenging task due to several reasons like complexity of networks and diverse devices, protocols, software etc [17]. The presence of a generic set of guidelines can be very useful in understanding the pros and cons of choosing the different technological elements for an IoT application. The guidelines can be best represented in the form of a reference architecture depicting the relation between the different building blocks. This section presents one of the most popular formats for IoT reference architecture. Typically, the architecture of IoT is divided into three basic layers [6],[3]: Things layer, Network layer and Application layer. To support modelling of IoT systems providing interoperability with applications of multiple parties or service providers we consider IoT architecture to be divided into four layers: 1) Things layer, 2) Network layer, 3) Platform layer, and 4) Application layer.





Common Attacks on IoT Systems: Attacks on IoT systems that mainly involve forging of device identity, data tampering and physical harm of sensing components [6, 18] are presented below. a) Node capture attacks: The threat actor can capture and control the IoT node or device. This allows replacing or manipulating hardware or software components in the node and potentially extracting credentials or other sensitive information. b) Malicious code injection attacks: In this attack, the threat actor can gain control of a node by injecting malicious code. The injected malicious code once executed can grant the threat actor access into the IoT system up to the extent of gaining full control of the IoT system. c) False data injection attacks: In this attack the threat actor can inject false data to replace original measurements of the device. Transmission of false data can return erroneous feedback commands or results which further affects the effectiveness of IoT applications. d) Physical Damage: In this attack hardware components are physically destroyed to make the device data unavailable. Some examples of the attack include de-packaging, destruction of flash memory etc. e) Sleep deprivation attacks: In IoT, devices or nodes that are battery powered are programmed to follow a sleep cycle to preserve battery life. Sleep deprivation attacks target to break the pre-programmed sleep cycle and keep the devices awake till the time the batteries are drained, rendering the devices unavailable.

CONCLUSION:

The integration of **IoT (Internet of Things)**, **automation**, and **advanced communication technologies** is revolutionizing industries, homes, and cities by enabling smarter, more efficient, and data-driven systems. IoT devices collect real-time data, automation systems process and act on this data, and seamless communication networks ensure timely and reliable information exchange. Together, these technologies enhance productivity, reduce human error, optimize resource usage, and create connected environments that are adaptive and intelligent. As these fields continue to evolve, they hold immense potential to transform the way we live and work, paving the way for a more interconnected and automated future.

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ENGINEERING FACTS

*The **Eiffel Tower** grows taller by about **15 cm in summer** due to metal expansion.*

AI LEGAL DOCUMENT ANALYZER

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ABSTRACT

In the fast-paced legal landscape, efficiency and accuracy are paramount. AI Legal Document Analyzers are emerging as game-changing tools, leveraging artificial intelligence to streamline the review, analysis, and management of complex legal documents. These systems use natural language processing (NLP) and machine learning to identify key clauses, detect risks, ensure compliance, and even suggest edits or summarize lengthy contracts—all in a fraction of the time it takes a human. Beyond improving speed and reducing human error, they empower legal professionals to focus on strategic tasks rather than manual review. This article explores how AI is transforming the legal industry, the technology behind these analyzers, and the ethical considerations surrounding their use.

INTRODUCTION TO AI IN LAW

The legal profession is known for its reliance on documents, from contracts and agreements to compliance records. Traditionally, analyzing these documents takes hours of careful reading and interpretation. With the rise of artificial intelligence, lawyers and firms are beginning to adopt new tools that can process large volumes of legal text quickly, making analysis not only faster but also more accurate.

How AI Document Analyzers Work

AI legal document analysers use advanced natural language processing to understand the structure, meaning, and context of legal writing. These systems are trained on vast collections of legal data, enabling them to

recognize clauses, highlight risks, and even suggest improvements in contracts. They can identify key terms that might otherwise be overlooked, saving valuable time and minimizing human error.

Benefits for Legal Professionals :

One of the most important advantages of AI in law is efficiency. Tasks that previously required several days of manual helps lower costs for clients and improves access to legal services.

Challenges and Considerations:

Although AI legal tools are powerful, they are not without challenges. Lawyers must ensure that these systems comply with privacy regulations and handle sensitive data securely. Additionally, AI is still a tool that requires human judgment to interpret final outcomes. The responsibility for decisions remains with the legal professional, meaning AI is best used as a support system rather than a replacement.

The Future of Legal Practice

As AI continues to improve, it is likely to become a standard part of legal practice. From analysing case law to assisting in litigation preparation, its applications are expanding quickly. Firms that embrace AI technology will have a competitive advantage, delivering faster, more reliable results for their clients. The AI legal document analyser represents not

review can now be completed in a fraction of the time. This means lawyers can dedicate more energy to strategy and client interaction rather than paperwork. Accuracy is another strength since AI tools reduce the likelihood of missed details or inconsistent analysis. Furthermore, by automating routine work, AI

technological innovation buttransformative shift in how legal work is approached.

Conclusion :

Artificial intelligence is reshaping the legal world in meaningful ways. By speeding up document review, enhancing accuracy, and cutting down costs, AI legal document analyzers are proving to be a valuable partner for legal professionals. The future will likely see closer collaboration between human expertise and machine intelligence, ensuring that justice is delivered with greater efficiency and precision.

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VIRTUAL POWER PLANT TOPIC MAGAZINE

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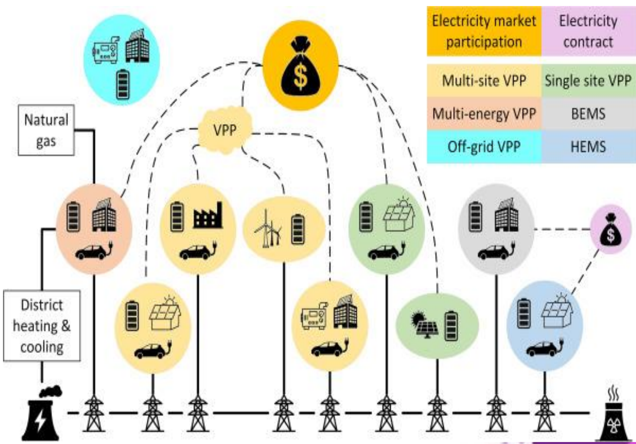
ABSTRACT

The growing global demand for clean, reliable, and affordable energy has given rise to innovative power management solutions. One such breakthrough is the Virtual Power Plant (VPP) a digital platform that integrates distributed energy resources such as solar panels, wind turbines, batteries, and electric vehicles into a unified, intelligent network. Unlike traditional centralized power stations, a VPP leverages advanced software, IoT devices, and artificial intelligence to optimize energy production, consumption, and storage in real time. This not only enhances grid stability but also reduces costs, promotes renewable energy adoption, and empowers consumers to actively participate in the energy market. With successful pilot projects in countries like Germany, Australia, and India, VPPs are rapidly emerging as a cornerstone of smart grids and sustainable cities, paving the way toward a carbon-free energy future.

INTRODUCTION

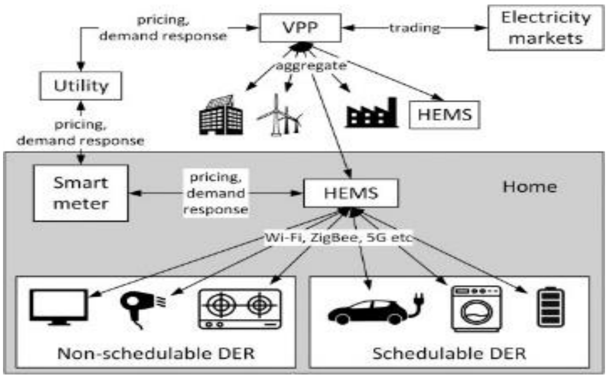
Electricity is essential for modern life, powering homes, schools, industries, and hospitals. Traditionally, large power plants using coal, gas, or dams supplied energy, but they caused pollution, high costs, and struggled to meet rising demand. Today, the shift toward renewable energy has introduced the concept of the Virtual Power Plant (VPP) a digital network that links solar panels, wind turbines, batteries, and electric vehicles to ENGINEERING Tion like one large power plant. Using smart software and communication, VPPs enable people to use, share, or sell electricity, making power cleaner, more affordable, and more reliable for the future.

OVERVIEW OF VIRTUAL POWER PLANTS



OVERVIEW OF DIFFERENT KINDS OF VPPS.

VPPs are classified by purpose and scale. Commercial VPPs sell extra power for profit, while Technical VPPs focus on grid stability. Hybrid VPPs combine both, like Tesla's project in Australia. At the user level, Residential VPPs link homes with solar, batteries, and EVs, while Industrial VPPs manage factory and office demands. These models provide both economic and technical benefits across households, industries, and the grid.



HIERARCHICAL CONTROL METHOD

The distributed control method has two levels: the VPP manages central communication, while DERs act as independent subsystems. This reduces monopoly and computation load but may cause conflicts. To address this, strategies like game theory, distributed algorithms, symmetric control, and sub gradient methods are applied to enhance coordination and efficiency.

will be key for smart cities and a carbon-free future.

COMPREHENSIVE CONTROL METHOD

The comprehensive control method combines centralized and distributed control in two levels. At the centralized level, the VPP coordinates agents' bidding strategies for market participation. At the distributed level, agents perform local optimization and submit results to the VPP, which issues the final coordinated operation plan for execution.

PRACTICAL IMPLEMENTATION OF A VIRTUAL POWER PLANT

Global VPP projects show renewable integration at all levels. Early projects like VFCPP, Smart pool, EDISON, and FENIX balanced renewables with storage and CHP. Market-based models (Power Matcher), automation (Web2Energy), and Dynamic VPPs (POSITYF) expanded applications. These highlight VPP potential, though cybersecurity remains a key challenge.

CONCLUSIONS

Virtual Power Plant (VPP) research has advanced with models for energy optimization, coordination, and market participation. Yet, most remain theoretical with limited real use. Future focus is on Multi-Agent Systems (MAS) in Cooperative VPPs, enabling autonomous local decisions, flexibility, and reduced central dependence, leading to smarter and more resilient energy systems.

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ENGINEERING FACTS

The word "engineer" comes from the Latin word ingenium, meaning "cleverness."

TRAFFIC SINGNAL AND CONTROL SYSTEM

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ABSTRACT

Efficient traffic management is crucial for reducing congestion, minimizing accidents, and improving urban mobility. ***Traffic Signal and Control Systems*** *play a vital role in regulating vehicle and pedestrian movement at intersections using intelligent control mechanisms. Modern systems go beyond simple timers—they now incorporate* ***sensors, cameras, and AI algorithms*** *to dynamically adjust signal timings based on real-time traffic conditions. This smart approach enhances traffic flow, reduces waiting times, and lowers vehicle emissions. With the rise of* ***smart cities****, the integration of technologies like* ***IoT*** *and* ***machine learning*** *into traffic control systems is shaping the future of urban transportation, making it safer, faster, and more sustainable.*

INTRODUCTION

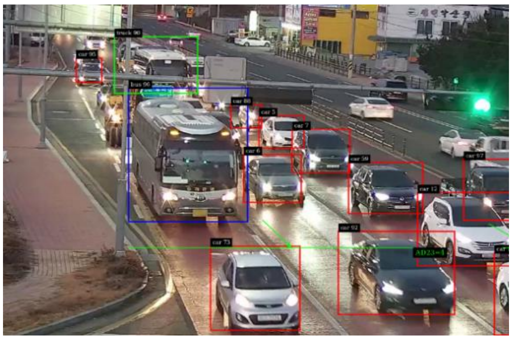
The rapid increase in population and vehicles has made traffic management a critical simple fixed-timer signals, which often caused delays and congestion. With the advancement of technology, traffic signal control systems have evolved to provide efficient solutions for managing road networks. These systems regulate the flow of vehicles and pedestrians, ensuring safety, reducing accidents, and improving traffic efficiency.

How Traffic Signal Control Systems Work

Traffic signal control systems operate using a combination of signal lights, controllers, and sensors. The traditional system works on a predefined cycle—red for stop, yellow for caution, and green for go. Modern systems, however, are equipped with vehicle detection sensors, cameras, and even Artificial Intelligence (AI) to analyse real-time traffic density. By adjusting signal timing dynamically, these systems minimize waiting time, reduce congestion, and optimize traffic flow at busy intersections.

Benefits of Traffic Signal Control Systems

Traffic signal control systems operate using a combination of signal lights, controllers, and sensors. The traditional system works on a predefined cycle—red for stop, yellow for caution, and green for go. Modern systems, however, are equipped with vehicle detection sensors, cameras, and even Artificial Intelligence (AI) to analyze real-time traffic density. adjusting signal timing dynamically, these systems minimize waiting time, reduce congestion, and optimize traffic flow at busy intersections.



Benefits of Traffic Signal Control Systems

One of the most important advantages of these systems is safety. By controlling traffic movement, they reduce the likelihood of accidents and conflicts at intersections. Efficiency is another major benefit, as traffic signals help vehicles move in an orderly manner, minimizing delays and fuel consumption. For pedestrians, they provide safe crossing points, improving overall road safety. Additionally, reducing idling vehicles helps lower pollution, contributing to a cleaner environment.

Challenges and Considerations

Despite their advantages, traffic signal control systems face challenges. High installation and maintenance costs can be a barrier for developing cities. Mal in sensors, cameras, or power supply can lead to confusion and heavy traffic jams. Furthermore, improper synchronization of signals across intersections may cause delays rather than solve them. These systems require regular monitoring and upgrades to effectively.

The Future of Traffic Management

With advancements in AI, IoT, and data analytics, traffic signal control systems are becoming smarter and more adaptive. Future systems may include features like real-time communication between vehicles and signals, priority lanes for emergency vehicles, and weather-adaptive control. Integration with smart city infrastructure will enable predictive traffic management, where congestion is prevented before it even occurs. Such developments will transform urban transportation, making it safer, faster, and more sustainable.

Conclusion

Traffic signal control systems are essential for maintaining order and safety on roads. From basic fixed-time lights to advanced adaptive networks, they have significantly improved traffic management. Although challenges remain, continuous technological innovation is making these systems more efficient and reliable. As cities continue to grow, smart traffic signal control will be a key factor in building sustainable and intelligent transportation systems.

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AUTONOMOUS FARMING ROBOT

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ABSTRACT

The rapid advancement of technology has paved the way for significant innovations in agriculture, particularly in the development of autonomous systems. This paper presents an overview of an Autonomous Farming Robot designed to optimize various agricultural tasks such as seeding, weeding, watering, and harvesting with minimal human intervention. By integrating sensors, machine learning algorithms, and robotic systems, the robot enhances productivity, reduces labour costs, and promotes sustainable farming practices. This project demonstrates the practical applications and benefits of robotics in modern agriculture, highlighting its potential to revolutionize traditional farming methods.

INTRODUCTION

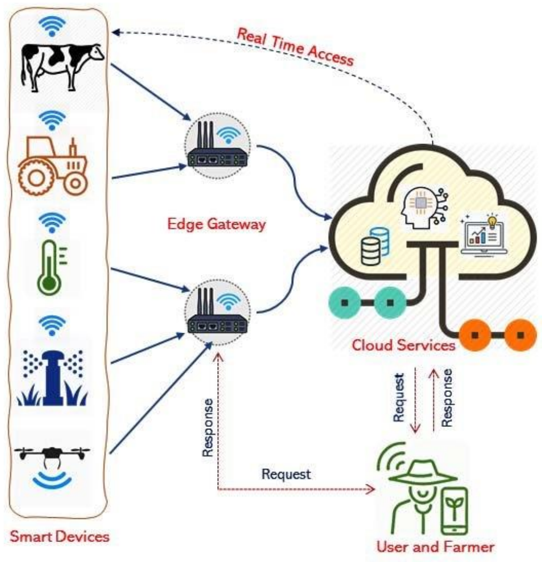
Agriculture has always been at the core of human civilization, but traditional methods are labour-intensive, time-consuming, and often inefficient. With the global population steadily increasing, there is a growing need to produce more food using fewer resources. Automation in agriculture addresses this challenge by incorporating advanced technologies to improve efficiency, precision, and sustainability.

An Autonomous Farming Robot is a machine capable of performing essential agricultural tasks independently or with minimal supervision. These robots use a combination of sensors (such as GPS, LiDAR, cameras), AI-based decision-making, and actuators to perform tasks like planting, soil monitoring, watering, spraying, and even detecting and removing weeds. The integration of autonomous systems into farming operations not only increases productivity but also contributes to reduced chemical usage, precise resource application, and lower environmental impact.

This project explores the diagonality, and impact of such a robot, aiming to support farmers in managing their fields more efficiently while addressing labour shortages and enhancing yield quality.

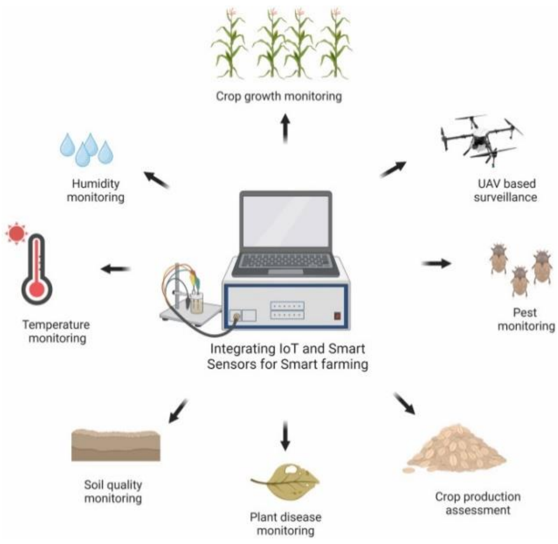
System Architecture

The system architecture of an autonomous farming robot refers to the complete structure of its hardware and software components, which must work together seamlessly. The core processing unit is often a microcontroller such as an Arduino or a more powerful board like the Raspberry Pi, which manages data from various sensors and issues commands to actuators and motors. This architecture also includes motor drivers, servo mechanisms, communication modules (such as Bluetooth, Wi-Fi, or LoRa), and a power system—typically powered by rechargeable batteries or solar panels for field use. The efficiency and reliability of the robot depend heavily on how well these components are integrated to operate continuously in outdoor agricultural environments**.**



Sensor Integration and Data Processing

A farming robot relies on various sensors to collect real-time information from its environment. Soil moisture sensors help determine water needs; temperature and humidity sensors monitor climate conditions; and vision sensors, such as cameras or LiDAR, are used for detecting crop health, identifying weeds, and navigating rows. These inputs are processed using data analysis techniques and artificial intelligence to make decisions without human input. For example, image processing algorithms can differentiate between crops and weeds, allowing the robot to remove weeds selectively. The quality of data processing directly impacts the accuracy and effectiveness of the robot's actions in the field.



Energy Efficiency and Power Management

Power consumption is a major concern for any autonomous system operating in remote or large outdoor areas. Farming robots are typically powered by lithium-ion batteries, which may be supported by solar charging systems to extend operational hours. Efficient power management ensures that energy is distributed smartly between different modules—such as motors, sensors, and communication systems—so the robot can continuously over long periods. Implementing low-power modes, sensor prioritization, and smart scheduling also helps conserve energy and increase the robot's autonomy in the field.

Conclusion

The implementation of autonomous farming robots is revolutionizing the agricultural landscape by introducing smart, efficient, and scalable solutions to age-old farming challenges. These robots not only help in reducing the burden on farmers but also ensure better resource management and improved crop yields. As technology continues to evolve, these machines are expected to become more intelligent, adaptable, and accessible to farmers of all scales. The project discussed in this paper serves as a foundation for future advancements in autonomous agriculture, contributing to the broader vision of sustainable farming and food security. While certain limitations such as cost, terrain adaptability, and maintenance remain, the long-term benefits of such innovations far outweigh the initial challenges. Continued research and development in this field will play a key role in shaping the future of agriculture worldwide.

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ENGINEERING FACTS

NASA engineers once used a felt-tip pen and duct tape to save Apollo 13 astronauts—proving simple solutions can save lives.

DEEP LEARNING FOR RENEWABLE

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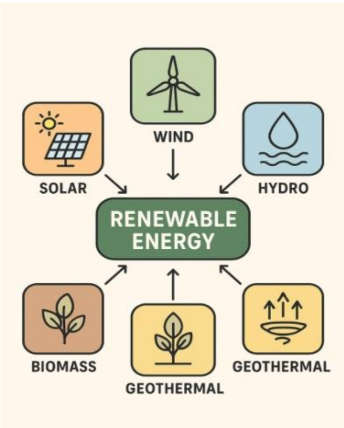
ABSTRACT

The transition to renewable energy sources such as solar, wind, and hydro is a global priority for sustainable development. However, the inherent intermittency, variability, and complexity of renewable systems create challenges for prediction, control, and optimization. Deep Learning (DL), a branch of artificial intelligence, has emerged as a transformative tool for addressing these issues. This paper provides an overview of DL techniques applied in renewable energy systems, highlighting their role in forecasting, fault detection, energy management, and grid integration.

INTRODUCTION

Renewable energy systems (RES) are essential to reduce dependence on fossil fuels and mitigate climate change. However, their widespread deployment is constrained by uncertain weather conditions, fluctuating outputs, and grid stability concerns. Conventional statistical models are often inadequate for capturing such nonlinear and dynamic patterns. Deep Learning, with its ability to learn complex data representations, offers promising solutions to these challenges.



Applications of DL

Renewable Energy Forecasting

Accurate forecasting of solar irradiance, wind speed, and energy demand is crucial for efficient scheduling and storage management.

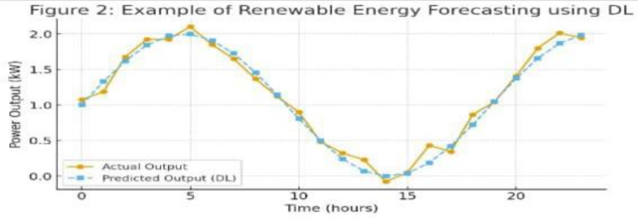
Convolutional Neural Networks (CNNs):

Used for satellite image analysis to predict solar power generation.

Recurrent Neural Networks (RNNs) and LSTMs:

Effective for time-series forecasting of wind speed and load demand due to their memory of sequential patterns.

Figure 2: Example of Renewable Energy Forecasting using DL



Fault Detection and Maintenance

Unsupervised DL models such as Autoencoders detect anomalies in sensor data from wind turbines or solar panels, enabling predictive maintenance and reducing downtime.

Energy Storage and Management

Deep Reinforcement Learning (DRL) optimizes the charging and discharging of batteries, balancing renewable output with grid demand.

Grid Integration and Stability

DL models aid in real-time grid monitoring and fault prediction, improving resilience. Hybrid architectures combining CNNs with RNNs can handle spatial-temporal data for smart grid operations.

Advantages and Challenges

- Ability to capture nonlinear and high-dimensional data.
- Improved forecasting accuracy over traditional methods.
- Real-time decision-making for smart grids.

Challenges

- Requirement of large, high-quality datasets.
- High computational cost of training complex models.
- Limited interpretability (black-box nature).
- Need for integration with domain knowledge for practical deployment.

Future Directions

- The next phase of research should focus on:
- Hybrid DL models combining physics-based approaches with data-driven learning.
- Transfer learning to reduce data requirements across different regions.
- Explainable AI (XAI) to improve trust and interpretability in energy applications.

Conclusion

Deep Learning offers a powerful set of techniques for enhancing renewable energy systems, from accurate forecasting to efficient grid integration. While challenges remain in data availability, computation, and interpretability, the synergy between DL and renewable energy promises to accelerate the transition toward a sustainable energy future.

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ENGINEERING FACTS

The fastest elevator in the world is in Shanghai Tower, moving at 20.5 meters per second (~74 km/h).

NEUROMORPHIC CHIPS FOR LOW-POWER AI PROCESSING

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ABSTRACT

Neuromorphic computing is an emerging paradigm inspired by the structure and dynamics of the biological brain. With the rapid expansion of artificial intelligence (AI) into edge environments—such as mobile devices, embedded systems, and low-power sensors—conventional AI processors increasingly face limitations in power efficiency and real-time performance. Neuromorphic systems address these limitations by employing event-driven computation, spiking neural networks, and in-memory processing to deliver intelligent behavior with minimal energy consumption. Unlike traditional von Neumann architectures, neuromorphic chips merge memory and processing to overcome latency bottlenecks, enabling ultra-low-power, on-device AI. This paper provides a comprehensive analysis of neuromorphic computing, exploring its architectural foundations, key chip implementations, recent technological advancements, and real-world applications. The work further discusses challenges hindering mass adoption, and outlines directions for future research that could solidify neuromorphic processors as a mainstream solution for AI at the edge.

INTRODUCTION

As artificial intelligence permeates everyday technologies, the demand for responsive, low-power AI computation has surged dramatically. From autonomous vehicles and mobile assistants to wearable health devices and smart home systems, the ability to process data locally and efficiently is becoming increasingly important. However, traditional AI accelerators such as graphics processing units (GPUs), central processing units (CPUs), and tensor processing units (TPUs) are inherently limited by their reliance on high-throughput, clock-driven processing, and memory architectures that are detached from the computational core. This disconnection leads to what is commonly referred to as the von Neumann bottleneck—a fundamental inefficiency wherein frequent data transfers between the processor and memory introduce latency and consume substantial energy.

Neuromorphic computing offers a radically different model by drawing inspiration from the biological brain. The human brain achieves impressive cognitive performance while consuming less than 20 watts of power, a feat attributed to its distributed, event-based processing and co-localized memory and computation.

Neuromorphic systems aim to emulate this behavior in silicon, using specialized architectures where units called neurons communicate via spikes, and computation is triggered only by relevant input events. This asynchronous and sparse operation model allows neuromorphic chips to continuously with power budgets orders of magnitude lower than conventional digital processors.

This shift in design philosophy aligns well with the emerging needs of edge computing, where devices must process sensor data in real time, often under strict power constraints. Neuromorphic processors promise not only energy efficiency, but also adaptability through on-chip learning, robustness in noisy environments, and real-time responsiveness. This paper explores the principles behind neuromorphic architectures, details the latest hardware implementations, examines benchmark results from recent studies, and evaluates the applicability of these chips in key domains including healthcare, robotics, and environmental monitoring.

Neuromorphic Architecture and Brain-INSPIRED DESIGN

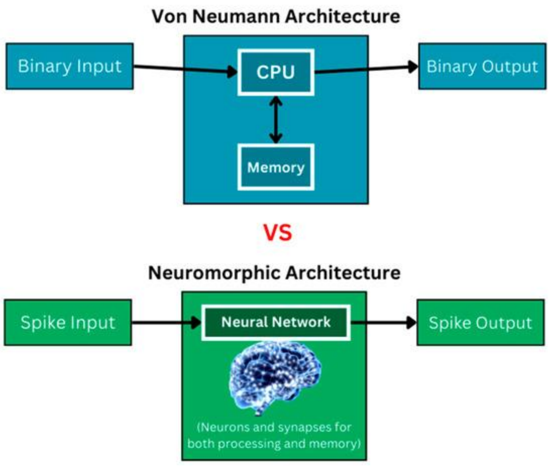
Neuromorphic architecture is defined by its biological parallel: the brain. At the lowest level, the brain comprises neurons that process signals and synapses that modulate signal strength between neurons. Neuromorphic chips aim to replicate this structure in hardware using artificial neurons and synapses. In particular, they are built around spiking neural networks (SNNs), which differ fundamentally from conventional artificial neural networks (ANNs). Instead of operating in discrete time steps with continuous activation , SNNs process data as asynchronous, binary spikes, with neurons firing only when certain voltage thresholds are reached. This design not only reduces computation but also reflects how biological neurons operate.

Each spiking neuron in a neuromorphic system maintains a dynamic internal state, commonly modeled as a membrane potential. When incoming spikes from other neurons accumulate and cause this potential to exceed a threshold, the neuron emits its own spike and resets. Communication between neurons is sparse and event-driven, which minimizes redundant operations and dramatically cuts down on energy usage. Importantly, SNNs incorporate a time dimension into processing, enabling them to capture temporal patterns more naturally than traditional ANNs.

Neuromorphic systems further distinguish themselves through their integration of memory and computation. In standard von Neumann systems, memory and logic are physically separate; data must be moved back and forth, consuming time and energy. Neuromorphic processors eliminate this overhead by using in-memory computing strategies, often realized through emerging memory technologies such as resistive RAM (RRAM), phase-change memory (PCM), and memristors. These memory elements serve dual roles as both storage units and computational operators, encoding synaptic weights and performing multiply-accumulate operations in place.

A critical feature of neuromorphic hardware is its asynchronous nature. Unlike digital CPUs and GPUs that operate on a global clock, neuromorphic systems are typically clockless, or event-driven, meaning that computation is performed only when a spike event occurs.

This drastically reduces idle power consumption and makes the system highly scalable. Communication within the network of neurons is achieved through address-event representation (AER), a method that encodes spike information in a format suitable for high-speed, low-power interconnects.

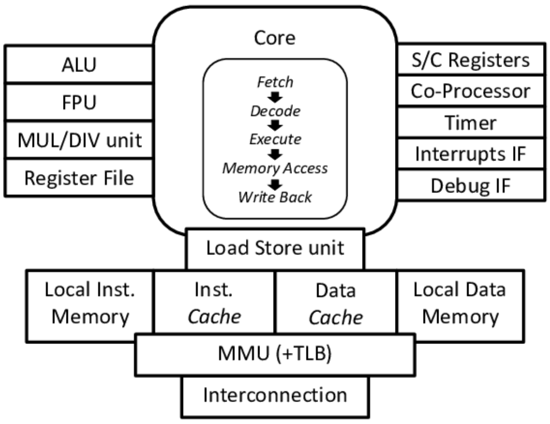


STATE-OF-THE-ART NEUROMORPHIC CHIPS

Several research and commercial initiatives have resulted in neuromorphic chips with varying degrees of biological realism and performance capabilities. Among the most prominent platforms is Intel's Loihi, a many-core neuromorphic processor that supports programmable neuron models, plasticity rules, and on-chip learning. Loihi implements over 130,000 digital neurons and 130 million synapses, and allows for real-time learning based on local spike-timing-dependent plasticity (STDP). It is particularly suited for adaptive applications where the network must update itself based on changing input patterns.

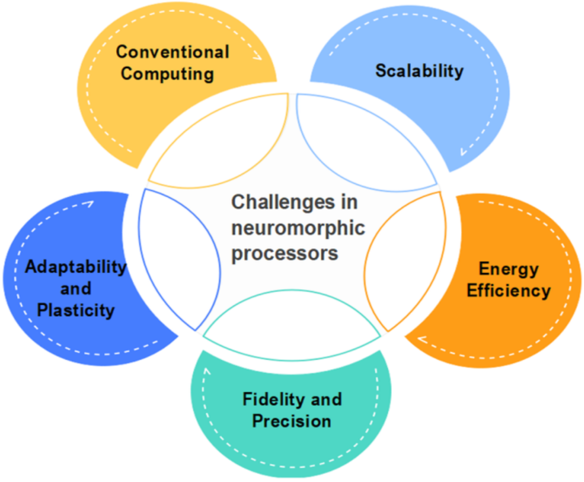
IBM's TrueNorth is another notable example. Unlike Loihi, which supports learning, TrueNorth is a fixed-weight system designed for inference. It consists of 1 million digital neurons and 256 million synapses, implemented using a scalable, ultra-low-power architecture. It has demonstrated successful deployment in vision and classification tasks, with power consumption under 100 milliwatts—substantially lower than any GPU- or CPU-based solution for similar tasks.

Commercial ventures such as BrainChip have also made significant strides. The Akida chip, produced by BrainChip, is a neuromorphic SoC optimized for edge AI applications. Akida supports on-chip training, incremental learning, and supports a range of sensory modalities including audio, vision, and time-series data. It is used in smart home devices, industrial safety systems, and wearable electronics.



Neuromorphic Learning Algorithms and Training Challenges

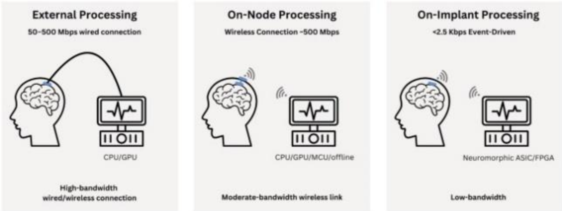
Several approaches have been proposed to address the training of SNNs. One strategy involves converting pre-trained deep neural networks (DNNs) into spiking networks. This technique, known as ANN-to-SNN conversion, relies on carefully mapping the continuous activations of ANNs into spike rates or spike timings. Although conversion methods can yield ally equivalent models, they often suffer from accuracy loss, especially in deep architectures or tasks involving fine-grained temporal precision. Moreover, these methods do not leverage the temporal dynamics inherent to spiking networks, potentially underutilizing the true capabilities of neuromorphic hardware.



An alternative and more biologically plausible method involves local learning rules, such as spike-timing-dependent plasticity (STDP). STDP adjusts the strength of synaptic connections based on the timing of pre- and post-synaptic spikes. If a pre-synaptic neuron fires shortly before a post-synaptic neuron, the connection is strengthened; if the order is reversed, the connection is weakened. While STDP aligns well with on-chip learning capabilities, especially in hardware like Intel's Loihi, it remains limited in its ability to train deep hierarchical networks without additional supervisory signals.

To bridge the gap between biological realism and training efficiency, researchers have also explored surrogate gradient methods. These techniques approximate the gradient of the spike activation with a smooth surrogate, enabling the use of gradient descent while preserving the spiking nature of the network. Surrogate gradient training has shown promise on classification benchmarks such as MNIST and CIFAR-10, but remains computationally intensive and is not yet standardized across hardware platforms.

Another area of active research is reinforcement learning for spiking networks. Neuromorphic reinforcement learning combines the temporal dynamics of spikes with reward-driven updates, allowing agents to learn from delayed feedback signals. This approach is particularly attractive for robotics and control systems, where decisions must be made based on sequential input over time. However, implementing such algorithms efficiently on neuromorphic hardware requires dedicated system-level support for memory retention, policy exploration, and gradient approximation.



Despite these efforts, the training ecosystem for SNNs is still in its infancy compared to the mature landscape of deep learning. Toolchains remain fragmented, and common machine learning libraries such as TensorFlow and PyTorch lack full support for spiking computation. Specialized frameworks like Brian, NEST, and BindsNET have emerged, but often require steep learning curves and lack integration with modern ML pipelines. Consequently, expanding the accessibility and usability of neuromorphic development environments is crucial for the broader adoption of these chips in academic and commercial domain.

conclusion

Neuromorphic computing represents a pivotal evolution in AI hardware, delivering low-power, adaptive, and event-driven intelligence honed for edge deployment. Despite compelling advantages in energy consumption and temporal processing, the future of neuromorphic technology hinges on continued progress in training methods, software tools, and hardware scalability. By addressing these challenges, and through possible integrations with traditional architectures, neuromorphic chips are well-positioned to support the next generation of sustainable, intelligent systems.

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ENGINEERING FACTS

Wearable electronics (like smart clothes and health sensors) are expected to grow into a $100+ billion market by 2025.

INTRODUCTION TO AI AND DIGITAL TWIN IN MORDEN ENERGY SYSTEM

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ABSTRACT

The global energy landscape is undergoing a rapid transformation driven by the need for sustainability, efficiency, and resilience. In this context, the integration of **Artificial Intelligence (AI)** and **Digital Twin** technologies is revolutionizing how modern energy systems are designed, monitored, and optimized. A **Digital Twin** is a virtual replica of a physical energy asset—such as a power plant, grid, or wind turbine—continuously updated with real-time data to simulate performance and predict potential failures. When combined with AI, these models enable advanced data analytics, predictive maintenance, automated control, and real-time decision-making. This powerful synergy enhances grid reliability, reduces operational costs, and supports the integration of renewable energy sources. As the energy sector embraces digital transformation, AI and Digital Twins are becoming key enablers of a smarter, more adaptive, and sustainable energy future

INTRODUCTION

With increasing system complexity and the demand for real-time monitoring, industries face challenges in predicting failures, reducing downtime, and improving efficiency. This project explores the **integration of Digital Twin with IoT, AI, and data analytics** to simulate, monitor, and improve physical systems. It has vast applications in **smart manufacturing, healthcare, energy systems, transportation**, and more—making operations smarter, safer, and more sustainable

WHY DIGITAL TWIN

- To bridge the gap between physical systems and digital intelligence.
- To support Industry 4.0 with real-time monitoring and prediction.
- To explore applications across sectors like healthcare and manufacturing.
- To tackle issues like data privacy, ethics, and system scalability.

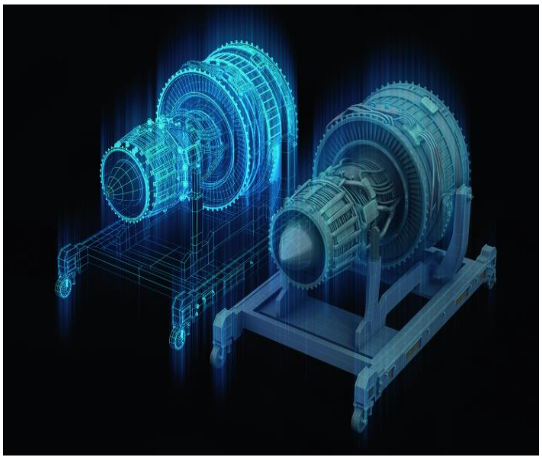
- To guide future-ready innovations and sustainable infrastructure.

ROLE OF AI IN ENERGY OPTIMIZATION

Artificial Intelligence plays a crucial role in analyzing vast amounts of real-time energy data. By predicting demand patterns, optimizing generation, and reducing transmission losses, AI ensures that power systems operate more efficiently. AI-driven forecasting also helps balance renewable sources like solar and wind, which are highly variable in nature.

INTEGRATION OF AI AND DIGITAL TWIN

When AI and digital twin technologies are combined, they provide a powerful decision-making framework. AI algorithms can process data from the digital twin to predict system failures, recommend maintenance schedules, and even suggest energy-saving measures. This integration reduces costs, extends asset life, and supports sustainable energy goals.



CONTRIBUTION TO A SUSTAINABLE FUTURE

Together, AI and digital twin technologies contribute significantly to building a cleaner, smarter, and more resilient energy system. They enable higher renewable energy integration, reduce carbon emissions, and ensure that energy is used more responsibly. Their contribution goes beyond efficiency—they are shaping the foundation of the future green economy.

DIGITAL TWIN IN INDIA

The government's "Sangam: Digital Twin“-2024 initiative focuses on future infrastructure planning using AI, ML, IoT, and 5G/6G. Pune, for example, is using digital twins for urban growth modeling and resource optimization.

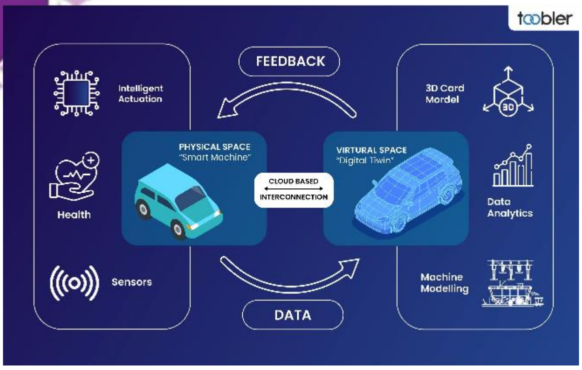
PROS & CONS

Efficiency and Reliability – Improves energy management through real-time monitoring and predictive insights.

Sustainability – Supports renewable energy integration and reduces carbon footprint.

High Cost of Implementation – Requires investment in advanced sensors, infrastructure, and skilled expertise.

Data Security Risks – Sensitive energy data may be exposed to cyberattacks.



Conclusion

Digital Twins are transforming how we design, monitor, and optimize systems in real time. While the potential is vast, challenges in standardization, integration, and security remain. Bridging these gaps will unlock smarter, more sustainable, and future-ready innovations across every industry.

"A digital twin is not just a model — it's a mirror to the future."

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ENGINEERING FACTS

Flexible and foldable displays are no longer futuristic—they're commercially sold in 2025 phones and gadgets.

DIGITAL TWIN-BASED MODELS FOR SOLAR PV PERFORMANCE MONITORING AND OPTIMIZATION

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ABSTRACT

The integration of Digital Twin (DT) technology with solar photovoltaic (PV) systems presents a transformative approach for real-time performance monitoring and optimization. Solar PV efficiency is influenced by dynamic factors such as irradiance, temperature, shading, and component degradation, which conventional monitoring methods often fail to capture accurately. Digital Twins create a virtual replica of the physical PV system, continuously updated with sensor and IoT data, enabling predictive maintenance, fault detection, and energy yield optimization. By simulating operational scenarios and analyzing system behavior in real time, DT-based models enhance reliability, reduce downtime, and support cost-effective lifecycle management. This study explores the development and application of Digital Twin-based models for solar PV systems, highlighting their potential to improve performance, efficiency, and sustainable energy management

INTRODUCTION

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Digital Twin Technology in Solar PV Systems

Digital Twin technology creates a virtual replica of a PV system that mirrors its physical counterpart. Its components include:

Sensors and IoT devices: Measure electrical output, voltage, current, temperature, irradiance, and other parameters.

Data analytics and machine learning: Process large datasets to detect performance deviations, predict failures, and optimize energy output.

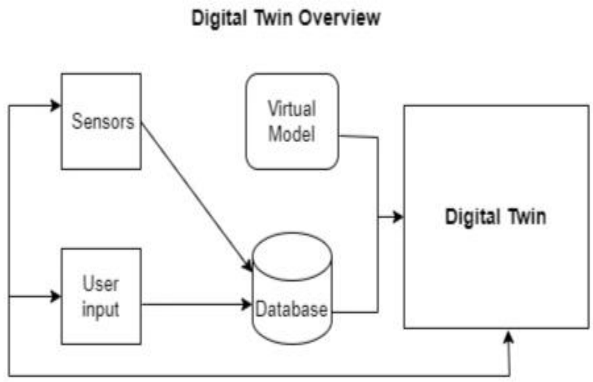
Simulation models: Allow operators to test operational strategies virtually before implementing them in the physical system.

By integrating these components, DT models provide an accurate representation of system performance under varying environmental conditions. This enables operators to identify faults early, reduce downtime, and improve energy yield.

Methodology for Digital Twin Implementation

THE IMPLEMENTATION OF A DIGITAL TWIN FOR A SOLAR PV SYSTEM TYPICALLY INVOLVES:

Data Acquisition: Installing sensors to collect real-time data on voltage, current, temperature, irradiance, and power output. Data Integration: Transferring collected data to a cloud-based or local database for processing. Model Development: Creating a virtual model of the PV system using simulation software or physics-based models. Analytics & Machine Learning: Applying predictive analytics and ML algorithms to forecast failures, optimize performance, and recommend maintenance. Visualization& Monitoring: Displaying real-time system performance through dashboards for operator. This methodology allows operators to simulate operational conditions, predict faults, and make informed decisions without physically interfering with the system.



Applications of Digital Twin in PV Systems

Digital Twin-based models offer multiple benefits for solar PV systems:

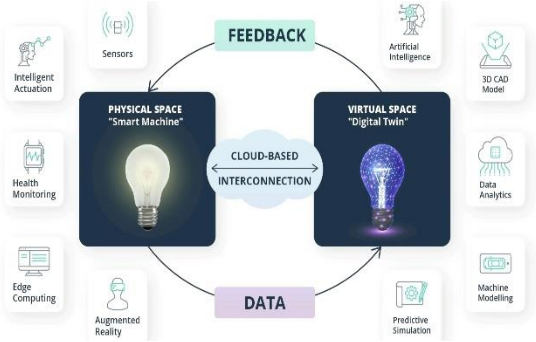
Real-time performance monitoring: Tracks system behavior continuously for better energy management.

Predictive maintenance: Forecasts equipment degradation, reducing unplanned downtime and maintenance costs.

Fault detection and diagnosis: Identifies anomalies such as shading, soiling, or inverter mal .

Energy yield optimization: Simulates different operating scenarios to maximize power generation.

Lifecycle management: Supports decisions on component replacement, cleaning schedules, and system upgradesThese applications enhance operational efficiency, reduce costs, and improve the reliability of solar PV systems.



CHALLENGES AND FUTURE DIRECTIONS:

Despite the advantages, Digital Twin technology faces several challenges:

High initial cost: Implementation requires sensors, data storage, and advanced computing resources.

Data management complexity: Large volumes of real-time data need efficient storage, processing, and security.

Integration issues: Combining DT models with existing PV systems and SCADA platforms can be complex.

Model accuracy: The virtual twin must accurately represent physical behavior, which requires continuous calibration and validation.

Future research may focus on integrating artificial intelligence, edge computing, and advanced predictive algorithms to improve DT accuracy and reduce costs, making this technology more accessible for small- and medium-scale PV installations.

CONCLUSION

Digital Twin-based models represent a transformative approach for monitoring and optimizing solar PV systems. By creating a dynamic virtual replica of the physical system, DTs provide real-time insights, predictive maintenance, and energy yield optimization. While challenges such as high costs and data management exist, ongoing technological advancements are likely to make DTs an integral part of smart, sustainable, and efficient solar energy systems. The adoption of Digital Twin technology supports the broader objectives of renewable energy development and intelligent energy management.

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AUTONOMOUS FARMING ROBOT

(ROBOTICS APPLICATION IN AGRICULTURE)

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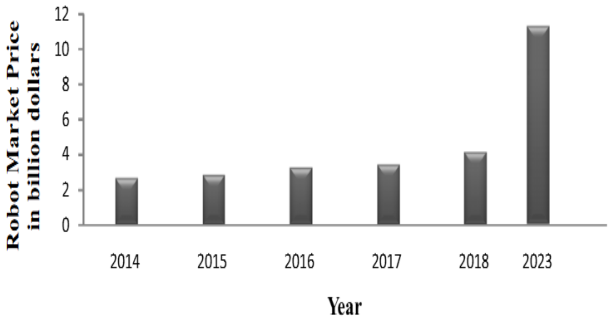
ABSTRACT

The Autonomous Forming Robot is an advanced robotic system designed to automatically shape and form materials with minimal human intervention. Utilizing sensors, actuators, and intelligent control algorithms, the robot can adapt to variations in material properties and environmental conditions, ensuring precision, efficiency, and consistency in manufacturing processes. Applications span construction, automotive, aerospace, and medical industries, where complex structures or components need to be fabricated with high accuracy. By reducing human labor, enhancing safety, and enabling continuous operation, autonomous forming robots represent a significant advancement in industrial automation and smart manufacturing technologies.

INTRODUCTION

The global population is rising rapidly, expected to reach 9.8 billion by 2050, while arable land, resources, and labour in agriculture are steadily declining. Climate change further reduces productivity, creating a serious food crisis. To meet growing demand, farming methods must evolve to produce more nutritious food with fewer resources.

Agricultural robotics offers a solution, addressing labour shortages, precision, and efficiency gaps where traditional machinery falls short. In India, where most farmers are small or medium-scale, affordable and adaptable machines are essential. The global market for agricultural robots is expanding rapidly—from US$ 2.6 billion in 2014 to an expected US$ 10 billion by 2023—driven largely by China, Korea, Japan, the USA, and Germany.



Source:https://www.mordorintelligence.com/

Figure 1: Value of agricultural robot market in the world.

DEVELOPMENT OF AGRICULTURAL ROBOT SYSTEMS

Agricultural robots are applied across crop farming, livestock, poultry, and aquaculture, performing tasks such as phenotyping, monitoring, mapping, crop management, and environmental control. In crop farming, they support tillage, grafting, planting, fertilizing, pollination, spraying, harvesting, and grading, while similar applications extend to animal farming and aquaculture. Research has advanced from open-field production to greenhouses and fully enclosed plant factories.

Robotic solutions are typically grouped into airborne, ground-based, and aquiclude systems. They can also be classified as **non-selective robots**, which perform tasks without distinguishing targets, and **selective robots**, which use sensing and machine vision to identify, locate, and act precisely on individual plants or animals.

Aspect	Type
Type of industry	Crop farming, livestock and poultry farming, aquaculture
	Phenotyping, monitoring, mapping, health protection, etc
Intelligent level	Remote-control, man-robot collaboration, full autonomous
Working mode	Selective, non-selective
Mobility	Stationary, mobile
Space	Aerial, ground, aquiclude

TABLE 1: CLASSIfiCATION OF AGRICULTURAL ROBOT SYSTEMS (JIN ET AL., 2021)

Robots are well-suited for frequent and risky farm tasks, reducing farmers' dependence on manual labour and exposure to health hazards. They are increasingly used for sowing, weeding, hoeing, spraying fertilizers and pesticides, cutting crops, and fruit picking. Small, automated robots can move between crop rows like self-driving vehicles, performing multiple operations with precision.

As agriculture becomes more high-tech, it is attracting youth, professionals, and investors, with many companies already developing robots and drones. These technologies are enhancing productivity in diverse ways, with specialized robots for soil testing, seed sowing, weed control, harvesting, fruit picking, grass cutting, and livestock care.

EXAMPLE: SOIL TESTING ROBOTS

Continuous cropping reduces soil nutrients, and farmers often apply fertilizers unevenly since nutrient levels vary across fields. Traditional soil sampling is labor-intensive and prone to errors of up to 20% due to inconsistent depth or location, leading to either excessive or insufficient fertilizer use. To overcome this, researchers have developed automated soil testing robots.

For example, Scholz et al. (2014) introduced *Boni rob*, an autonomous robot equipped with a soil penetrometer that operates in both manual and automatic modes. Similarly, the European Union's *Vine Robot* project, involving partners from France, Italy, Germany, and Spain, created an autonomous system to measure vineyard parameters like soil moisture, grape yield, and vegetative growth, providing accurate, on-the-go data to guide winemaking decisions (Saiz et al., 2017; Xu et al., 2021).

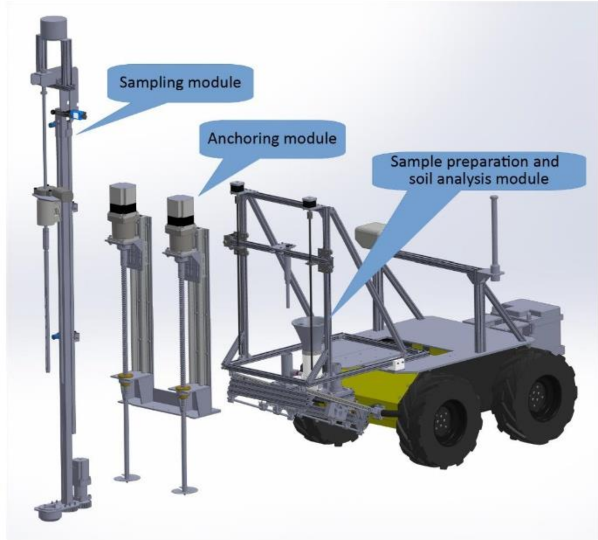


Figure 2: Soil Testing Robots

Robots for Seed Sowing and Transplanting

High-quality seeds can increase yield by 20–25%, but proper spacing and depth are critical. Small robots are ideal for sowing and transplanting in small fields where large machines cannot operate. Using devices like dibblers, they can also handle vegetable seed sowing. Modern robotic systems integrate sensors (ultrasonic, IR), actuators, motors, microprocessors, communication, and data processing for precise seed placement (Kumar & Ashok, 2020; Jayakrishna et al., 2018; Nagdeve et al., 2020; Naik et al., 2016; Santhi et al., 2018).

The Indian Institute of Agricultural Research developed a **precision robotic planter** for bold seeds, operating on Cartesian coordinates for accuracy. Measuring 1.75 m × 2.10 m × 1.25 m and weighing 460 kg, it runs on four 70Ah batteries for 4 hours, covering fields batch by batch with wireless mobile commands. Trials included sowing paddy and maize (IARI, 2018). Similarly, Santhi et al. (2018) created a **sensor and vision-based robot** capable of field navigation, localization, and seed planting using GPS, onboard vision, and mapping for autonomous operation.

Figure 2: Seed Sowing and Transplanting Robots

CONCLUSION

Agricultural robots are evolving to meet the needs of modern farming, supporting tasks like soil testing, sowing, weeding, harvesting, pruning, fruit picking, hay cutting, phenotyping, and livestock care. They are especially effective in weeding, hoeing, and fruit harvesting, often outperforming human labour. Multi-use robotic platforms have also emerged, handling diverse operations with GPS, sensors, and growing integration of artificial intelligence.

As an emerging market, agricultural robotics offers vast potential for productivity gains, employment, and innovation. By making farming smarter and more efficient, these technologies not only boost production but also attract the younger generation to agriculture.

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Pramod Kumar Sahoo,Dilip Kumar Kushwaha, NrusinghCharanPradhan, YashMakwana,

AUTONOMOUS WAREHOUSE ROBOT

P. Dharshan

Third year EEE, E.G.S. Pillay Engineering college

ABSTRACT

Autonomous mobile robots (AMRs) have gained rapid attention over the past decade. Unlike AGVs, they navigate independently without fixed infrastructure. Advances in hardware and software make them practical for warehouses, reducing human effort and fatigue in repetitive tasks. This review covers AMR hardware, control, system management, and examples of current producers. Future research and potential warehouse applications are also discussed.

INTRODUCTION

Building on this, modern AMRs leverage advanced sensors, AI, and real-time path planning to navigate dynamic warehouse environments safely. By working alongside humans, they streamline material transport, reduce motion waste, and improve overall productivity. Despite high upfront costs, the combination of efficiency gains and reduced labor fatigue makes collaborative AMR systems a valuable investment for smart warehouses.

Fig. 1 Human-robot collaboration in the warehouse

1.1 REVIEW METHODOLOGY

This paper reviews the current state of AMRs in warehouses, covering research studies, company hardware, and software. Literature was sourced from IEEE Xplore, Google Scholar, and company searches using keywords like “AMR,” “warehouse,” “localization,” “path planning,” and “fleet size.” Papers from 2013–2024 were prioritized. The review is organized into sections on hardware/software developments, robotic control, system management, future research, and conclusion.

2.2 PROCESSORS

AMRs require real-time data processing to operate in dynamic environments. Advances in AI-specific CPUs, GPUs, and accelerators like Jetson Xavier NX, LuxonisDepthAI, and Google Coral have made edge computing feasible. These processors are essential for decentralized algorithms, enabling each robot to make quick decisions and communicate efficiently.

2.3 BATTERIES

High-capacity, fast-charging lithium-ion batteries have improved AMR operations, with some models achieving full charge in under an hour. Wireless charging reduces downtime, although continuous 24-hour operations still require careful resource management. Environmental concerns remain, as recycling lithium-ion batteries is limited and challenging.

3.1 LOCALIZATION

AMRs use sensors like LiDAR, 3D cameras, and encoders for localization. SLAM builds probabilistic maps of robot positions, while hybrid navigation combines long-range sensors (GPS, ultrasonic) with short-range sensors (magnetic strips) for precise positioning. Examples include ForwardX Max robots using SLAM and visual-based positioning.

3.2 ARTIFICIAL INTELLIGENCE (AI)

AI allows AMRs to navigate dynamic environments, avoiding or maneuvering around obstacles autonomously. Techniques include visual classification, machine learning, neural networks, fuzzy logic, and deep reinforcement learning, often combined with sensor fusion to maintain accuracy when some sensors fail.

3.3 PATH PLANNING

Path planning guides robots from start to goal while avoiding obstacles. Common algorithms include bug algorithms, vector field histograms (VFH/VFH*), artificial potential fields, and heuristic methods like genetic algorithms, fuzzy logic, and particle swarm optimization. Multi-robot coordination uses hybrid approaches combining neural networks, reinforcement learning, and consensus strategies to optimize navigation and avoid collisions.

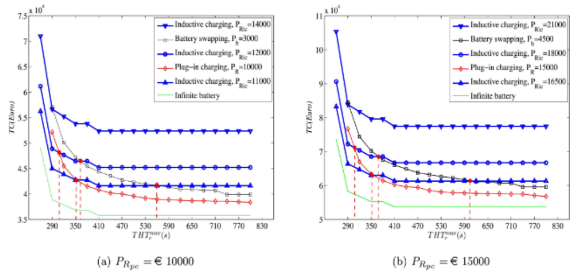


Fig. 2 Robot battery cost comparison

FLEET SIZE DETERMINATION

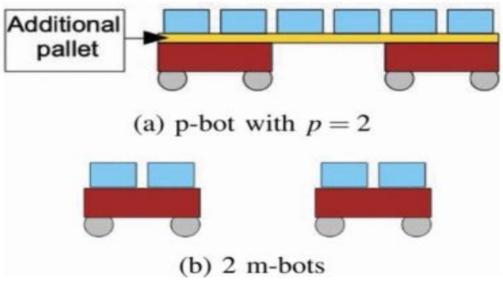


Fig. 3 Robot cooperation with p and m-bots

Correct fleet sizing is crucial to maintain consistent lead times. Too many robots or personnel can create bottlenecks, while too few can delay shipments. Software like MiRFleet from MiR coordinates up to 100 robots, managing traffic and priorities with minimal programming.

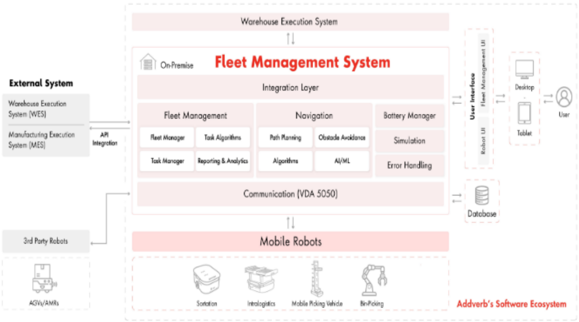
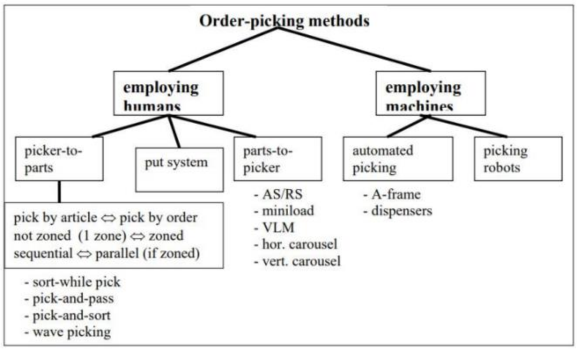


Fig. 4 Fleet management system

HUMAN-ROBOT PICKING METHODS



CONCLUSION

Autonomous mobile robots (AMRs) have significantly improved warehouse performance and productivity. Advances in localization, sensors, batteries, and AI—such as genetic algorithms and deep reinforcement learning—have enabled decentralized decision-making. Human-robot collaboration, optimized layouts, and picking strategies reduce fatigue and enhance efficiency. While most research focuses on warehouses, applications in outdoor or hazardous environments remain limited. Overall, AMR research is rapidly evolving and transforming manufacturing operations.

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ENGINEERING FACTS

Flexible and foldable displays are no longer futuristic—they're commercially sold in 2025 phones and gadgets.

LORAWAN AND WIRELESS TECHNOLOGIES

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Final year EEE, E.G.S. Pillay Engineering college

ABSTRACT

The Internet of Things (IoT) enables device connectivity for monitoring and control, often using Low Power Wide Area (LPWA) protocols for long-range, low-power communication. Among these, LoRa has gained significant attention due to its efficiency and LoRaWAN-based star-of-stars topology. This work evaluates LoRa in indoor and outdoor environments, showing stronger performance outdoors. Results also highlight that elevating gateways for line-of-sight improves signal quality and extends communication distance.

INTRODUCTION

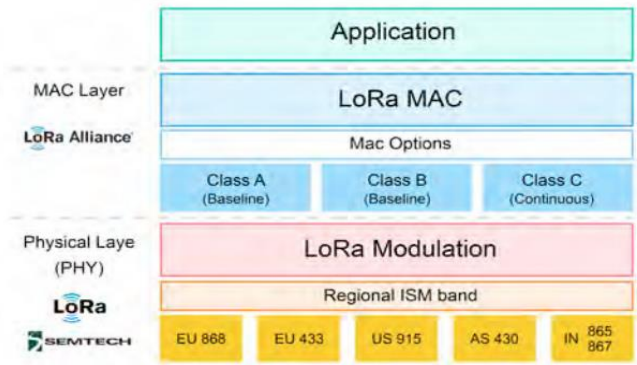
The Internet of Things (IoT) enables smart solutions across fields like industry, healthcare, homes, and agriculture through sensor nodes, gateways, and servers. Each application demands specific device design and communication protocols, with agriculture requiring long-range, low-power nodes. Low Power Wide Area Networks (LPWAN) address these needs by offering long battery life, large coverage, and simple single-hop communication. Among LPWAN technologies, LoRa has gained strong research interest due to its scalability and efficiency. This work evaluates LoRa and LoRaWAN in indoor and outdoor environments, analyzing coverage, SNR, and packet reception.

OVERVIEW OF LORA AND LORAWAN

LoRa is a long-range, low-power wireless technology designed for extended battery life, massive device connectivity, and robust communication. It has two layers: the physical layer, based on Chirp Spread Spectrum (CSS) by Semtech, and the MAC layer, standardized as LoRaWAN. Operating in unlicensed ISM bands (e.g., 863–870 MHz in Europe), LoRa supports multiple channels, duty cycles, and spreading factors, balancing data rate and sensitivity.

FIG. 1. LORA TECHNOLOGY PROTOCOL STACK.

LoRaWAN follows a star topology, where devices communicate only with gateways connected to a central server. It defines



three classes of end-devices: Class A for bidirectional communication with energy-saving sleep cycles, Class B for scheduled transmission windows synchronized with beacons, and Class C for near-continuous reception, suitable for low-latency applications with constant power.

3. RELATED WORK

Several studies have examined LPWAN performance under different conditions.

Cattani et al. (2017) showed that temperature and humidity affect RSSI, while Ferré (2017) analyzed packet loss and collisions in LoRaWAN. Interference from neighboring gateways was addressed by Voigt et al. (2016) using directional antennas. Capacity limits due to duty cycle and densification were discussed by Adelantado et al. (2017). Petäjäjärvi et al. (2017) found mobility above 40 km/h reduces reliability, and Mikhaylov et al. (2016) showed uplink rates drop significantly with distance from the gateway.

4. EXPERIMENTAL SETUP AND RESULTS

The setup included a WiMOD Demo Board (end-node) with a LoRa iM880B module and sensors, and a WiMOD Lite Gateway connected to TTN. Tests were conducted indoors and outdoors, where the end-node transmitted temperature and potentiometer data using Cayenne LPP. Messages were sent via LoRa to the gateway and forwarded to TTN in real time. Both devices operated in Class A mode at 868 MHz, 125 kHz channel size, SF12, coding rate 4/5, and 14 dBm transmit power.

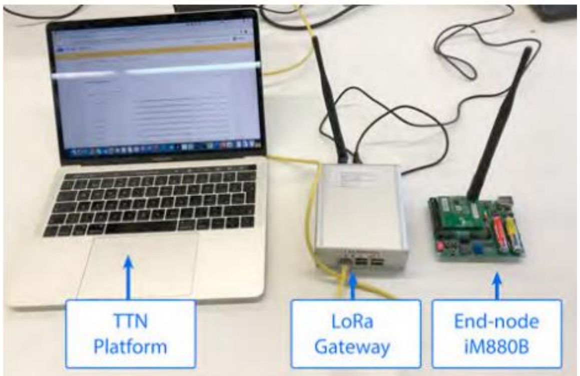


Fig. 2. Experimental setup used for the test:

4.1 INDOOR ENVIRONMENT

The indoor experiment was conducted at the University of Valencia, with the gateway placed in Block 3 (Electronic Engineering, level 2) and the end-node tested across various blocks and floors. At each location, 15 messages were transmitted, measuring RSSI, SNR, and packet reception rate. Results showed variations depending on building layout and signal conditions, with LoRa able to demodulate even below noise floor levels.

RP [%] = 100 × (NACK/ NAP)

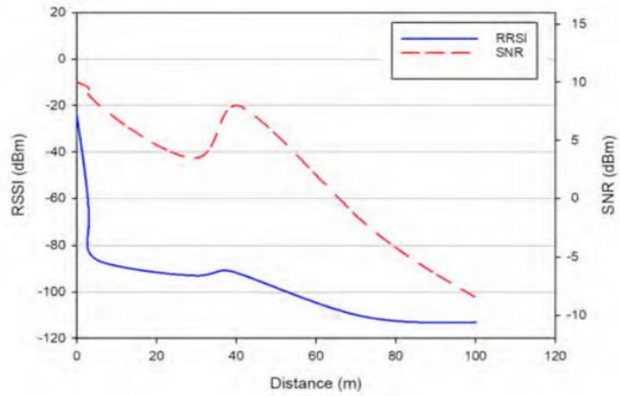


FIG. 5. RSSI AND SNR AS OF DISTANCE IN AN INDOOR ENVIRONMENT

4.2 OUTDOOR ENVIRONMENT

The outdoor test was carried out in Valencia city with the gateway placed on a 10th-floorbalcony (40 m high) and the end-node moved across various street locations (P1–P11). At each point, 15 packets were transmitted, and RSSI, SNR, and packet reception (RP) were measured. Results showed RSSI decreased with distance, with first losses at 295 m (P4), while beyond 415 m some locations still achieved 100% delivery. Variations in packet loss despite shorter distances highlight the impact of environmental factors like absorption, diffraction, and scattering on signal strength.

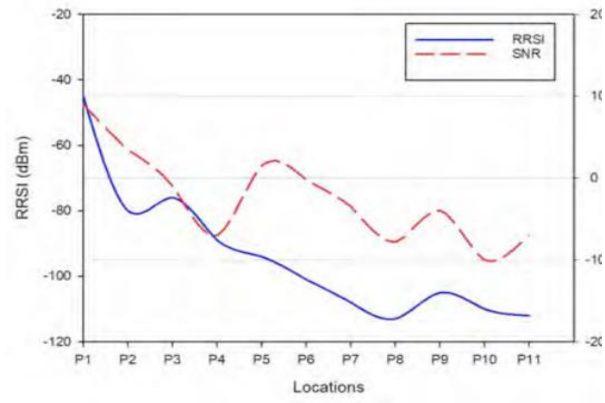


Fig. 8. Outdoor RSSI and SNR as of distance

CONCLUSION

The experiments showed that LoRa performs well indoors for small buildings (up to ~70 m) but suffers from signal loss in denser structures, while outdoor tests maintained good quality up to 800 m, further improved by elevating gateways. Packet loss increased beyond -120 dBm, though SNR had less impact. Overall, LoRa and LoRaWAN prove effective for IoT applications needing long-range, low-power connectivity without heavy data transfer.

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Mohamed Saban ∗ Otman Aghzout∗∗ Leandro D. Medus ∗ Alfredo Rosado

ENGINEERING FACTS

In 2016, scientists made the world's smallest engine using a single calcium ion.

DESIGN THINKING PATENTS

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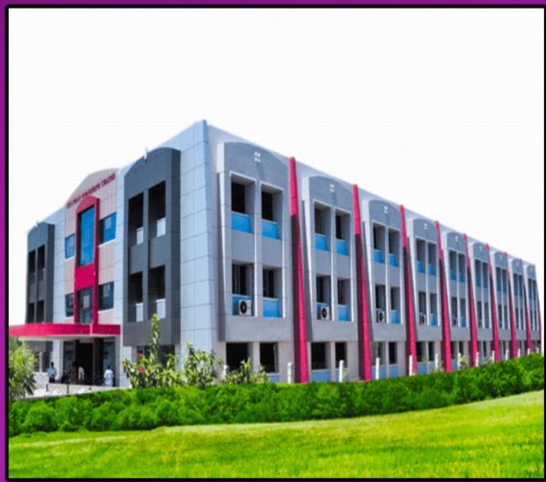

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