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Artificial intelligence applied for micro smart grids: A literature review

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ABSTRACT Energy production schemes are subject to a constant scientific and technological revolution due to fluctuating social, economic, and political changes. The integration of new ways of power generation, electrical and electronic elements that consume the power generated and require specific energy quality policies, electric vehicles, energy efficiency, energy management, architecture reliability, bidirectional communication, and resilience are some challenges control strategies face. Technology and science have supported and faced this challenge in energy production schemes, especially in intelligent electrical microgrids. This article presents a comprehensive review of the state of the art of artificial intelligence techniques that are applied to face the various challenges of operation, control, and coordination in a Micro Smart Grids (MSG). In particular, how artificial intelligence develops and faces challenges in central areas in an MSG architecture.

KEYWORDS Smart grid; Artificial intelligence; Smart control; Energy production schemes; Electrical microgrid

1. Introduction

Coal power production is the most important scheme in terms of electric power generation, satisfying around 40 % to 50 % of world energy consumption (Ashraf et al., 2022). Figure 1 shows this type of generation plant's primary operative structure.

First, heavy machinery (which works with diesel) extracts coal in extensive quantities to generate energy in power plants. Mined coal is ground and loads on trucks that travel hundreds of kilometers to the power plant. In these, coal is burned to release heat along with CO_2 and other pollutants. Heat is used to heat water, generating steam which turns a turbine, obtaining electricity (Fig. 1a). Once energy is generated, voltage is increased through electrical transformers in transmission substations (Fig. 2b). In this point, power in high voltage levels is transmitted over long distances through transmission lines (Fig. 1c). These lines are interconnected with distribution substations, where transformers reduce the voltage to low voltage levels (Fig. 1d). Finally, energy is distributed short distances through the distribution grid (Fig. 1e), which uses smaller transformers to reduce the voltage to appropriate levels for end users (Fig. 1f). Coal-based production scheme has certain drawbacks; one of the most important is that the energy must travel several kilometers from the plant to the point of consumption where 100 % of the power generated to the end user only 60 % or 50 % reaches (Putrus and Bentley, 2016). The coal-Based Production Scheme creates tons of greenhouse gases (Kumawat et al., 2018). In 2020, nearly 49.4 billion tons of these gases were generated, and 73.2 % corresponded to the Coal-Based Production Scheme (Gasparotto and Da Boit Martinello, 2021). In addition, forecasts of the energy required for coming decades grow immeasurably, which is a disturbing fact, coupled with the projections of the depletion of fossil fuel reserves (Ram et al., 2018). All these points motivate the scientific community to search for different sustainable solutions for energy generation and reduce the dependence on the Coal-Based Production Scheme, reducing the negative impact of greenhouse gases on the planet.

In recent years, more than 27 % of electrical energy worldwide has been produced by Distributed Energy Resources (DER) (Foruzan et al., 2018). DER comprises different renewable energy sources like wind turbines and solar panels, providing electrical energy from natural resources such as the sun, wind, or ocean waves. DER refers to small-scale power generation and storage systems close to the point of consumption, as opposed to coal power production located far away from consumers (Samanta et al., 2021). The use of DERs has become increasingly popular in recent years due to their potential to improve grid resiliency, reduce transmission losses, and lower carbon emissions. DERs can also provide consumers with greater energy independence and reliability, especially during power outages or other disruptions to the grid (Moreno Jaramillo et al., 2021).

The interoperability between DER, power electronic systems for voltage control or conversion, and electrical and electronic loads that consume the generated energy comprise an Electrical Microgrid (EMG) architecture. An electrical microgrid is a localized electrical network that produces, distributes, and consumes electrical power in a small area. It can operate independently of the larger electrical grid or be connected. The structure of an EMG is shown in Fig. 2. An EMG is composed of different DERs

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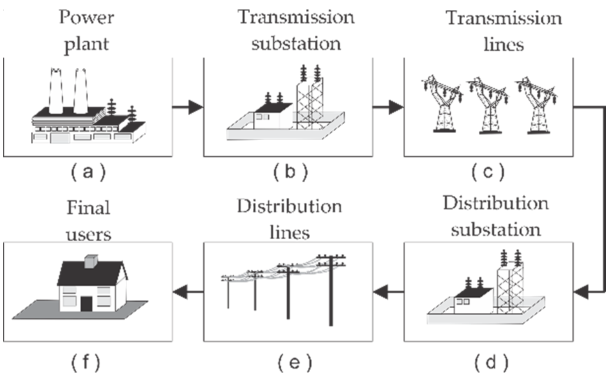

Figure 1: Coal-based production scheme.

not only limited to renewable resources such as photovoltaic or wind systems and also various non-renewable resources, such as fuel cells and diesel generators, can be found in an EMG (Dashtdar et al., 2022). The energy management system (EMS) presents multiple advantages, such as reactive power support to improve the voltage profile, decentralization of the energy supply, integration of thermal load for cogeneration, auxiliary energy services, and response to demand (Camarinha-Matos, 2016). EMS also reduces line losses and outages in the transmission and distribution system. EMG has some limitations, such as the high investment cost in the infrastructure, which is gradually compensated for control and storage systems (Liu et al., 2018b).

2. Micro smart grid

The concept of an Electrical Microgrid (EMG) has evolved along with the development of human beings and their needs in electricity demand. A Micro Smart Grid (MSG) is a type of electrical microgrid that incorporates advanced communication, sensing, and control technologies to optimize the operation and management of the local energy system (Yoldaş et al., 2017). Figure 3 shows a diagram roughly explaining the contexts by which traditional electrical microgrids evolved to MSG and how the characteristics of these structures evolved.

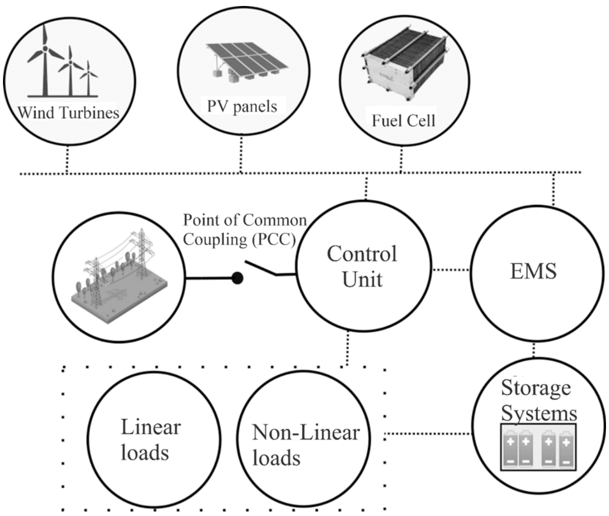

Figure 2: Traditional architecture of an EMG.

In the technological field, great technological entropy is experienced up to the present time at various levels, communications, materials, computers, and microcontrollers, among others. An example is the need for a set of Information and Communication Technology (ICT) components for two-way communications. Methodologies and tools emerged to add to the infrastructure, such as the Internet of Things or smart meters (Devidas and Ramesh, 2022). The diversity in distributed power generators demands control and coordination strategies among distributed generators. Finally, fundamental advances in power electronics have revolutionized traditional electrical microgrids to what are Micro Smart grids. In the political sphere, the gears that started the evolution of conventional electrical microgrids reside in policies and market demands for quality and energy management with consumers. Derived from this, the incentives and protections for consumers in taxes and price regulations have made more people join in consuming clean energies, which increases the use of Micro Smart Grid. In the social sphere, there are situations such as the need for green energy and the increase in energy demand; they are the main incentives for using electrical microgrids. At the same time, the consumer presents the need for excellent quality, reliability, consistency, security, and privacy in the infrastructures (Marzal et al., 2018). This point returns to the technological one; due to the quality requirements in electrical energy technology, its development influences intelligent control strategies.

The formal definition of MSG is the collection of all the technologies, concepts, and topologies. It approaches that allow the hierarchies of generation, transmission, and distribution to be replaced by an end-to-end, organically intelligent, and fully integrated environment where the Business processes objectives and the needs of all stakeholders are supported by the efficient exchange of data, services, and transactions (Abdulnasser et al., 2022). In Fig. 4, a diagram is presented of essential elements in the architecture of an MSG. These elements also represent a scientific and techno-logical challenge and affect the interoperability of an entire MSG system.

These areas summarize the architecture and challenges in an MSG. Each of these challenges has different levels of complexity due to the variability in loads, generation, consumption, and hardware elements, among other factors. Variability increases the complexity of these challenges, which is why artificial intelligence has become a sufficiently robust tool to face technological evolution and scalability. The contributions of artificial intelligence to meet the different challenges in each field are diverse. Figure 5 shows a graph of the number of contributions per year of artificial intelligence in the Micro Smart grid; this search was performed with Scopus Preview, the largest database of abstracts and citations of peer-reviewed literature: scientific journals, books, and conference proceedings.

The search criteria for these articles were limited to the keywords of this article, such as artificial intelligence, intelligent algorithms, microgrids, and integrated micro-

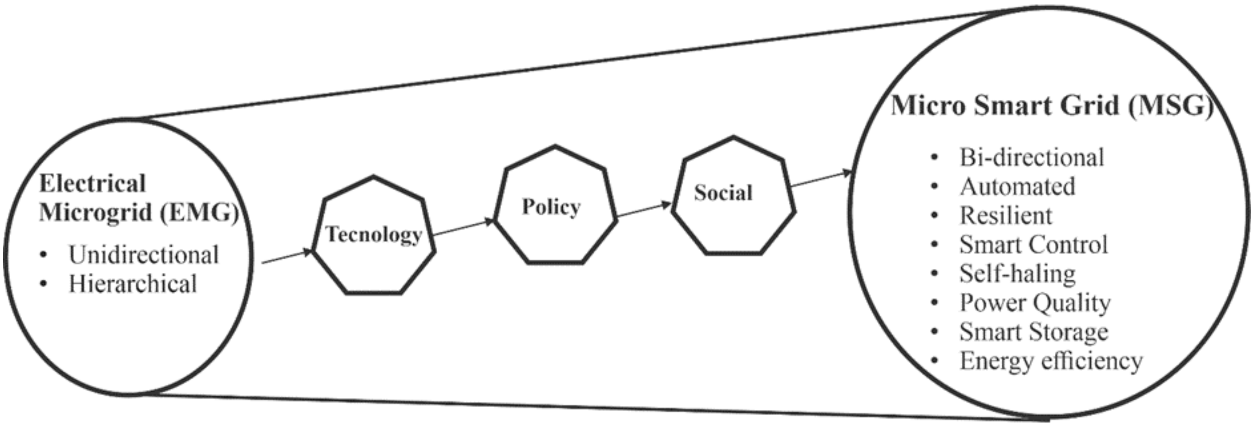

Figure 3: Evolution of electrical microgrids to micro smart grid.

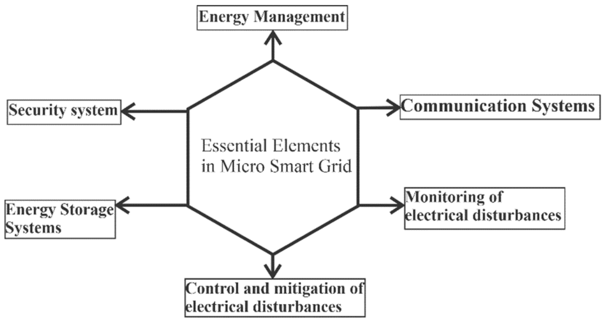

Figure 4: Elements of micrograms.

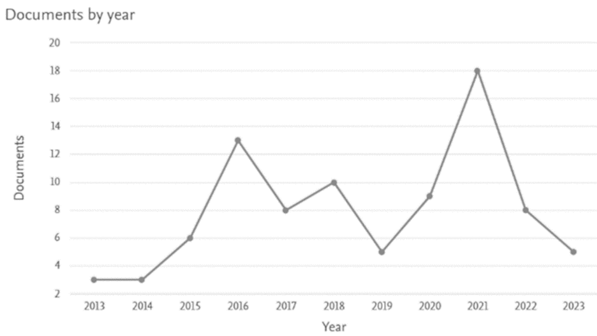

Figure 5: Scopus preview search engine results.

grids, and to quantify only journal articles.

In this context, this article analyzes and studies the trends, challenges, difficulties, results, and methodologies of the articles quantified in Figure 5 for the areas mentioned in Fig. 4. This study aims to show the importance of the studies in clean energy generation, the scientific, technological, and social impact of this type of article, and the reflections and contributions in different areas of smart grids.

This paper is divided into several sections. Section 1 presents the introduction, and section 2 a brief description of the Micro Smart Grid. Section 3 briefly introduces the discipline of artificial intelligence, its subfields, and their differences. Section 4 analyzes and studies artificial intelligence in energy management. Section 5 shows how artificial intelligence monitors and detects electrical disturbances. Section 6 offers intelligence to control and mitigate electrical disturbances. Section 7 studies and analyzes the intelligent algorithms applied to the sizing of storage systems. Section 8 presents the algorithms that address the challenges in cybersecurity and communication to maintain the interoperability of the entire Micro Smart Grid. Section 9 presents the analysis and discussions of the previous points, showing the overall picture of artificial intelligence in Micro Smart grids. Finally, Section 10 offers the conclusions of this work.

3. Artificial intelligence and smart algorithms

The concept of artificial intelligence (AI) was born in the 50s and is defined as the discipline within computer science responsible for giving machines the ability to exhibit human-like intelligence and decision-making abilities. Artificial intelligence allows computers to perform tasks that traditionally require human intelligence, such as recognizing patterns, making decisions, learning from experience, etc. (Russell et al., 2010). Machine Learning (ML) is one of the artificial intelligence divisions that teaches machines to learn from data. It is a method of data analysis that automates the construction of analytical models, which allows computers to improve their performance on a task automatically. Methodologies such as random Forrest, decision trees, simple linear regression, multiple linear regression, the k-nearest neighbors algorithm, also known as KNN or k-NN, and neural networks with simple architecture are part of Machine Learning (Goldenberg et al., 2019). Deep Learning (DL) is a subfield within AI and ML that uses artificial neural networks to learn from extensive, complex data. These models are trained using large amounts of data to perform various tasks, such as image recognition, electrical signals, voice, and video. Some models are Recurrent Neural Networks (RNN) used to process sequential data such as natural language, Generative Adversarial Networks (GAN) used in images or music, and Convolutional Neural Networks used in im-

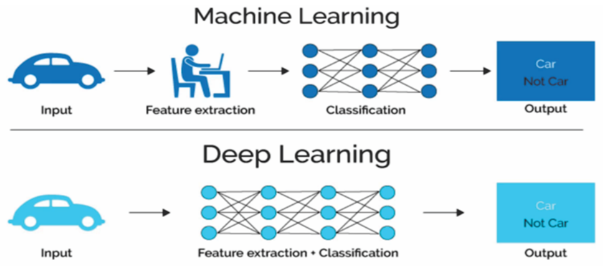

Figure 6: Comparison of neural architectures between machine learning and deep learning.

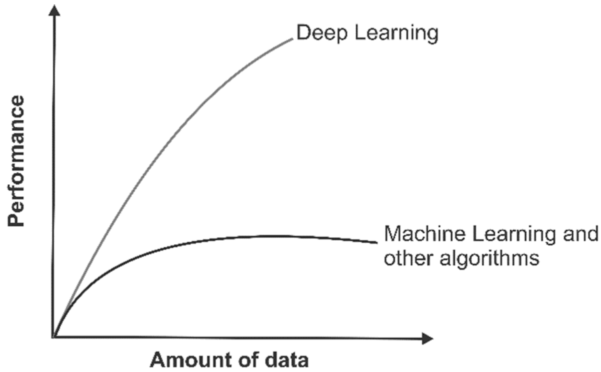

Figure 7: Performance comparison between deep learning and other intelligent strategies.

age classification, signal classification, and processing, and video processing tasks, among others (Mayo and Leung, 2018). The difference between ML and DL is the complexity in models and computational consumption, as shown in Figure 6, where a classification task is performed. There is a big difference in the number of tasks DL performs compared to ML (Currie and Rohren, 2021).

In addition to differences in architecture and the number of tasks, differences are observed in computational consumption, the amount of data to be used for learning algorithms, and the performance or precision of these two sub-fields, as shown in Fig. 7 (Tapeh and Naser, 2023).

In AI, learning refers to the ability of a machine, computer, or algorithm to improve its performance in a specific task through experience. AI implies designing and developing algorithms capable of learning through data and making predictions based on learning. AI learning involves teaching a computer how to perform a task by feeding the computational algorithm example, feedback, and guidance. There are different types of learning, such as:

- Supervised learning: The machine or computer algorithm provides a labeled data set, where each input is associated with a corresponding output. The machine learns to associate the inputs with the outputs in the examples.
- Unsupervised learning: The computational algorithm receives unlabeled data and must find patterns or structures independently. The grouping and the reduction of dimensionality implemented often in signs or images are examples of this type of learning.
- Semi-supervised learning combines supervised and unsupervised learning, where the machine receives labeled and unlabeled data. Use the labeled data to learn how to map inputs to outputs, and then use the unlabeled data to refine understanding of the patterns in the data.
- Reinforcement learning This type of learning involves learning through trial and error while interacting with an environment. The machine is rewarded or punished based on its actions and learns to make decisions that maximize its reward over time.

In the field of artificial intelligence, another essential subfield is evolutionary computing, used mainly for optimization tasks; this field focuses on the design of algorithms and techniques inspired by biological evolution to solve complex problems computationally, and often due to the nature of the problem ML and DL could be little tools suitable to be used. The central idea of evolutionary computation is to create automated and autonomous solutions using methodologies that simulate evolutionary processes, such as natural selection, mutation, crossing, and genetic recombination (Braik, 2021). Evolutionary computation is a powerful technique for solving complex problems inspired by evolutionary processes in nature and using computational techniques to optimize solutions through generations and natural selection. Figure 8 shows the general methodology of evolutionary computation algorithms. It is important to mention that this may vary due to the different behaviors of different species in their evolutionary process (Braik, 2021).

4. Smart algorithms for energy management

Energy management in MSG has been an important problem in electricity generation schemes and distributing the generated energy intelligently between loads and the storage system i. An important aspect of MSG is the balance between energy supply and demand. In addition to balancing supply and demand, the management system must meet particular goals such as emission reduction, charge and Discharge efficiency in the storage system, operational costs, and energy Storage Costs (Ahmad Khan et al., 2016). The energy management and administration system, the Energy Management System (EMS), must cover the objectives. The EMS of a Smart microgrid encompasses supply and demand side management while satisfying system constraints for an economical, sustainable, and reliable MG operation (Hajebrahimi et al., 2020). As a result, the management system is a complex system that, according to several authors, is not a problem that can be easily solved with the design and development of a mathematical model. For this, an evolutionary strategy is necessary to adapt to changes in generation and consumption and simultaneously be robust enough to analyze and process the multiple variables that affect the behavior of EMS (Raya-Armenta et al., 2021). Due to these, various

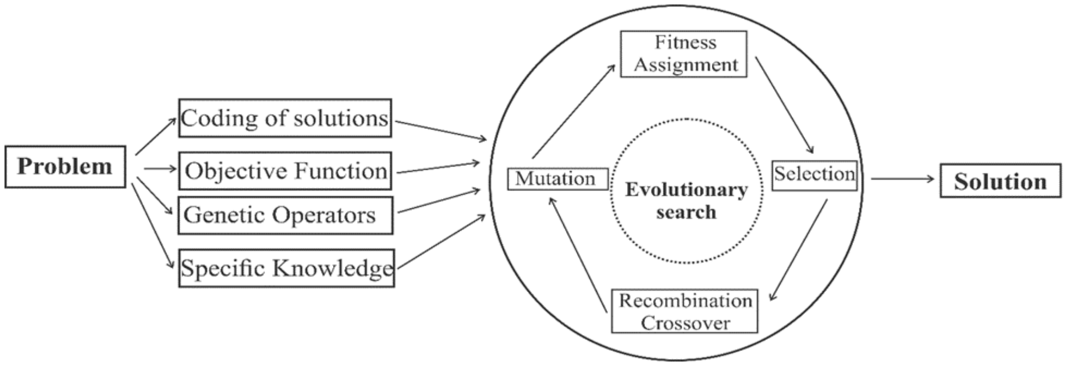

Figure 8: The general methodology of evolutionary computing.

Table 1: Smart algorithms for energy management.

Paper	Contribution	Techniques Used	Key features
Expert energy management of a micro-grid considering wind energy uncertainty (Motevasel and Seifi, 2014).	The proposed multiobjective system coordinates energy generation and consumption through meta-heuristic strategies.	Algorithm Bacterial Foraging Optimization (MBFO).	An interactive fuzzy satisfaction method is also used to simulate the trade-off between conflicting goals (cost and emission).
An emission constraint environment dispatch problem solution using the Whale Optimization Algorithm (Trivedi et al., 2016).	Total cost minimization and total emission are obtained for all included sources.	Whale Optimization Algorithm (WOA).	The results obtained with WOA give better cost reduction in fewer iterations as compared to the Gradient Method (GM), Ant Colony Optimization (ACO), and Particle Swarm Optimizer (PSO), which shows the effectiveness of the given algorithm.
Battery Energy Management in a Microgrid Using Batch Reinforcement Learning (Mbuwir et al., 2017).	Solves the challenge of finding a closed-loop control policy to optimally program the operation of a storage device to maximize the self-consumption of local photovoltaic production in a microgrid.	Reinforcement Learning (RL).	Unlike the others using live data, the strategy in this article uses a database for its development.
Towards Real-Time Energy Management of Multi-Microgrid Using a Deep Convolution Neural Network and Cooperative Game Approach (Samuel et al., 2020).	The proposal is based on the multiobjective approaches of other studies, such as genetic algorithms, fuzzy logic, and traditional neural networks.	Deep convolutional neural network.	The development of the control methodology is implemented in a multi-micro grid.
Efficient Energy Management in a Microgrid with Intermittent Renewable Energy and Storage Sources (Ramli et al., 2019).	A new metaheuristic optimization algorithm inspired by actual sporting events.	Most valuable player algorithm (MVPA).	Determine the optimal scheduling of different DER, battery storage, and grid power based on the selected scenario.
Power Management Strategy Based on Adaptive Neuro Fuzzy Inference System for AC Microgrid (Fekry et al., 2020).	Adaptive methodology for different scenarios of energy generation and consumption.	Adaptive neuro-fuzzy inference system (ANFIS).	A robust system to face any possible scenario in addition to having an adaptive and multiobjective feature.
Optimal Energy Management for Microgrids Considering Uncertainties in Renewable Energy Generation and Load Demand (Wu et al., 2020).	Formulated for a daily optimization timeline with one-hour steps, and is solved using the metaheuristic approach based on ant colony optimization (ACO).	Ant colony optimization.	Actual data and parameters obtained from a practical microgrid platform in Atlanta, GA, USA, are used to formulate and validate the proposed energy management approach.

A rule-based energy management scheme for long-term optimal capacity planning of grid-independent microgrid optimized by multiobjective grasshopper optimization algorithm (Bukar et al., 2020).	This algorithm is inspired by nature for long-term capacity planning of a grid-independent microgrid incorporating a wind turbine, a photovoltaic, a battery (BT) bank, and a diesel generator (D gen).	Grasshopper optimization algorithm (GOA).	The multi-target strategy minimizes the cost of energy (COE) and deficiency of power supply probability (DPSP).
A Novel Robust Smart Energy Management and Demand Reduction for Smart Homes Based on the Internet of Energy (Alhasnawi et al., 2021).	Methodology with intelligent and evolutionary algorithms developed in an embedded model with wireless communication.	Grey wolf optimizer (GWO), artificial bee colony (ABC) optimization algorithm-based Time of Use (ToU).	Reduction in energy losses between 25 % and 50 %, tests carried out with different loads and intervals of consumption and generation.
Novel Gaussian flower pollination algorithm with IoT for unit price prediction in peer-to-peer energy trading market (Sahoo et al., 2021).	Real-time methodology for energy management in electrical microgrids.	Flower pollination algorithm and machine learning.	Its computational efficiency is very high, a promising feature for real-time field implementation.
Decision tree-based optimization for flexibility management for sustainable energy microgrids (Huo et al., 2021).	A systematic method to generate the microgrid dispatch rule base to match as much as possible the control performance obtained by complete mixed-integer optimization.	Decision tree (DT).	Its computational efficiency is very high, a promising feature for real-time field implementation.
A Novel Deep Reinforcement Approach for IIoT Microgrid Energy Management Systems (Dridi et al., 2022).	Internet of Things methodology and architecture to manage energy to different systems and loads of a microgrid.	Deep Reinforcement Neural Network.	High-precision methodology with evolutionary learning, a feature that can help with scalability in the generating scheme.
Machine Learning Short-Term Energy Consumption Forecasting for Microgrids in a Manufacturing Plant (Slowik and Urban, 2022).	Universal forecasting tool for energy consumption by end-use consumers.	Long short-term memory (LSTM)-layer-based artificial neural network.	The model is characterized by high prediction capability, and it predicted energy consumption with a mean absolute error value of 0.0464.
Distributed energy sharing algorithm for Micro Grid energy system based on cloud computing (Su and Shi, 2023).	System peak and integrated Demand Response (DR)with Energy Management System (EMS) in a commercial Microgrid.	Data Analytics and Machine Learning.	The energy storage system (ESS) charges without sharing 125 MW per hour, and with power sharing from 200.5 to 300.5 MWh, higher electricity consumption of selling side price 8 kWh, buyer side price 10 kWh, the overall system throughput increased 5 %, total power transactions 20 kW, cost savings 8 % compared to other methods.

strategies based on intelligent methodologies have been proposed. Table 1 presents the most relevant works in chronological order, the contribution of this methodology, and some key points.

5. Smart algorithms for monitoring electrical disturbances

Electromagnetic phenomena that disturb electrical power quality in systems with renewable generators are called power quality phenomena or disturbances. These phenomena that affect power quality (PQ) originate for different reasons, for example, the constant integration of power generators over all those that tend to be unstable such as solar or wind. These disturbances could cause a high cost in equipment malfunction within the infrastructure (Ribeiro et al., 2018). In addition, also the nature of some loads, which could become non-linear loads, such as welding machines, electric arc furnaces, solid state switching devices, rectifiers and inverters, lighting controls, computer and data processing equipment, equipment of protection and relays, are the causes of the disturbances that affect the PQ (Cai et al., 2019). Figure 9 shows the electrical disturbances that generally occur in the MSG and affect the quality of electrical energy.

Monitoring, detecting, and analyzing this phenomenon is essential in electrical quality studies of MSGs and any power generation system. However, this task is not an easy challenge; several electrical disturbances are ultra-fast and

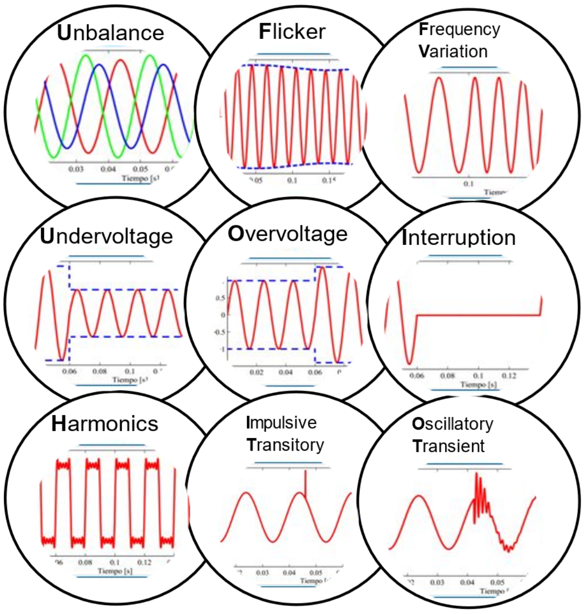

Figure 9: Electrical disturbances.

not very noticeable to the human eye, among other characteristics. Due to this, artificial intelligence has played an essential role in monitoring, detecting, and analyzing electrical disturbances. Generally, the methodology for classifying disturbances consists of the signal characteristics extraction phase and the classification phase with a methodology based on artificial intelligence. Table 2 presents the most relevant works in recent years. It is essential to mention that, especially in this branch of the study of microgrids, the methodologies could be more varied and varied. As a result, a selection of works was made based on scientific and technological contributions.

6. Smart algorithms for the control and mitigation of electrical disturbances

Power quality measures, analyzes, and improves the bus voltage to maintain a sinusoidal waveform at the nominal voltage and frequency (Li et al., 2021). The definition of Power Quality Disturbances (PQDs) is the deviation of voltage and current from their ideal sinusoidal shape (Hingorani, 1995). The origin of PQDs and their effects are diverse and extensive to discuss. Table 3 presents a summary of the causes and consequences of PQDs.

Electrical disturbances are stochastic, so the control strategies are robust, adaptive, and with a high response time. The revolution in control strategies for compensating electrical disturbances has a wide diversity of strategies to face the challenge of compensating disturbances. Compensating for electrical disturbances is of the utmost importance to preserve the quality of electrical power that the loads consume from the generators within the MSG architecture. Artificial intelligence has revolutionized control strategies for compensation, especially in simultaneous disturbances. Table 4 shows the most important contributions and developments in recent years for compensating electrical disturbances with artificial intelligence strategies.

7. Smart algorithms for energy storage systems

The objective of an Energy Storage System (ESS) is to deal with intermittent distributed generators. Storage systems can store energy during periods of high availability and forward it when there is a power shortage. Other benefits of using microgrid storage systems include providing ancillary services and improving power quality (Fossati et al., 2015). One of the main problems in the distribution, control, and coordination of the ESS is dimensioning. The sizing problem involves finding the ESS optimal power and energy capacities to minimize the microgrid operating cost. In turn, to reduce the operating cost of the microgrid, unit commitment, and economic dispatch problems must be resolved (Kichou et al., 2022). This combinatorial optimization problem lends itself to being solved with strategies within the field of computer science, from which several methods have been proposed. Table 5 presents the most relevant scientific and technological aspects and, above all, the design and development of the proposals.

8. Smart algorithms for communication systems and security systems

Communication's main objective is the microgrid's interoperability (Kondoro et al., 2021a). Moreover, security guarantees the data's availability, integrity, and confidentiality. The communication system is responsible for collecting, transmitting, and processing the data that travels wirelessly or wired through the network (Mohan et al., 2015). Communication and cybersecurity are vital for the correct and coordinated operation of the entire intelligent electrical system; therefore, an efficient data communication system is needed for continuous, fast, reliable, and accurate information transfer without disturbances and disconnections (Kondoro et al., 2021b). The effectiveness of a communication protocol is evaluated, such as data speed, coverage area, quality of service, reliability, latency, and power consumption (Kounev et al., 2015). The attacks on de communication and security system are:

- Attacks on data availability: Data accessibility is essential, especially for controlling power electronic converters in smart microgrids, especially in island mode and transients. The main objective of this type of attack is to block or delay communication in the structure. Examples of this type of availability attack are Denial of Service (DoS) and Distributed Denial of Service (DDoS). Usually, they send spam repeatedly to exhaust the processing of the routers, bandwidth, or servers (Rana and Abdelhadi, 2020).
- Attacks on data integrity: Signal readings must be reliable. If not, there could be severe problems such as voltage and frequency regulation, power and energy management, island detection, and resynchronization. These types of attacks are the most common and are called stealth attacks. An example of this type of attack is false data injection (FDI) cyberattacks. In MSG, these types of attacks are

Table 2: Smart algorithms for monitoring electrical disturbances.

Paper	Contribution	Techniques Used	Key features
Power Quality Disturbances Feature Selection and Recognition Using Optimal Multi-Resolution Fast S-Transform and CART Algorithm (Huang et al., 2016).	Multi-resolution fast S-transform (OM-FST) is implemented to extract the characteristics of the signals and classification and regression tree (CART) algorithm to determine the type of electrical disturbance in the voltage wave.	CART Algorithm.	The methodology presents a precision percentage between 87 % and 97 %, even with certain signal noise decibels.
A novel deep learning method for the classification of power quality disturbances using a deep convolutional neural network (Wang and Chen, 2019).	A closed-loop deep-learning method for electrical disturbance classification.	Deep convolutional neural network.	The convolutional model reduces the dimensionality of the signal to minimize computational consumption and increase the response time speed.
A Sequence-to-Sequence Deep Learning Architecture Based on Bidirectional GRU for Type Recognition and Time Location of Combined Power Quality Disturbance (Deng et al., 2019).	Sequence-by-sequence deep learning architecture based on the bi-directional closed recursive unit (Bi-GRU) for type recognition and temporal location of the combined power quality disturbance.	Sequence-to-Sequence Deep Learning.	The accuracy of type recognition is over 98 % for synthetic and real signals with noisy environments.
A New Convolutional Network Structure for Power Quality Disturbance Identification and Classification in Micro-Grids (Gong and Ruan, 2020).	The methodology comprises several elements of artificial neural networks in a single architecture to detect, classify and process different electrical disturbances.	New Convolutional Network Structure.	The network consists of a five-layer one-dimensional modified Inception-residual network (ResNet) (1D-MIR), a three-layer full connection layer, and a deep convolutional network.
A Novel Deep Convolution Neural Network and Spectrogram Based Microgrid Power Quality Disturbances Classification Method (Wang and Chen, 2019).	A Deep Convolution Neural Network (CNN), consisting of 2-D convolution layers, batch normalization, dropout, and maximum pooling, is designed to capture characteristics, speed training, and reduce overfitting.	Novel Deep Convolution Neural Network.	The methodology's performance ranges between 96 % and 97 %, even with multiple disturbances and signal noise.
Detection and classification of multiple power quality disturbances in Microgrid networks using the probabilistic-based intelligent classifier (Suganthi et al., 2021).	The hybrid methodology comprises different elements within the field of machine learning. Strategically, other methodologies' advantages were used for classifying multiple electrical disturbances.	A probabilistic-based intelligent classifier formed by Neural network Multi-Layer Perceptron (MLP), Support Vector Machine (SVM), and Naive Bayes (NB).	The precision percentage ranges between 66 % and 99 %. The variation in precision is because the author implements various machine learning models to carry out a study and analysis. As a multi-perception neural network, support vector machine and the Naive Bayes model. All within the artificial intelligence subfield of machine learning.
Adaptive Salp Swarm Algorithm as Optimal Feature Selection for Power Quality Disturbance Classification (Chamchuen et al., 2021).	Evolutionary methodology for data dimensionality reduction and neural classificatory predictive model for electrical disturbances.	Adaptive Salp Swarm Algorithm and probabilistic neural network.	Reduce 76 features to 12 significant features.
A Hybrid Approach Based on Principal Component Analysis for Power Quality Event Classification Using Support Vector Machines (Saxena et al., 2022).	Classification strategy using Hilbert transform and Wavelet transform with support vector machine.	Support Vector Machine (SVM).	The authors implement two feature reduction techniques to detect elements in ultrafast disturbances usually presented in disturbances.

Fault Classification with Convolutional Neural Networks for Microgrid Systems (Pan et al., 2022).	Fault detection mechanism from scalograms	Convolutional Neural Networks.	The trained classifier has an average training accuracy of 99.1 % for SA MG and 97.7 %.
A machine learning approach based on a decision tree algorithm for the classification of transient events in a microgrid (Banerjee and Bhowmik, 2023).	The identification and classification of different possible transient conditions in microgrid	Decision tree (DT) algorithm	The algorithm detects and discriminates each transient event with 100 % accuracy.
Deep learning-based multi-model ensemble method for classification of PQDs in a hydrogen energy-based microgrid using modified weighted majority algorithm (Bayrak et al., 2023).	Proposed to identify power quality disturbances.	Multiple deep classifiers with a modified Weighted Majority Voting (WMV)-based method.	The authors mention noise immunity as their methodology.

Table 3: Analysis of electrical disturbances.

Disturbance.	Source	Effect
Interruption	They result from electrical power, inverter failures, and errors in the MRE control systems (Igual and Medrano, 2020).	In general, they affect electronic and lighting equipment, and, in some cases, they can damage electronic soft start tools and control systems if the proper protections are not in place (Igual and Medrano, 2020).
Undervoltage or Sag	They mainly originate from a load switching (ON) or a capacitor bank switching (OFF) (Gong and Ruan, 2020).	They produce a significant heat loss in induction motors due to the increase in current. In capacitor banks results in a decrease in output power (Gong and Ruan, 2020).
Overvoltage or Swell	It occurs as a result of load switching as load switching (OFF) or switching a capacitor bank (ON) (Igual and Medrano, 2020).	It can cause electronic equipment and electrical appliance failures (IEEE, 2019).
Harmonics and Flicker	Due to the non-linear characteristics of the equipment and loads in the electrical structure (Igual and Medrano, 2020).	It causes overheating of rotating and static machines such as motors and transformers, as well as in current-carrying conductors, as well as causing premature breakdown and harmonic resonance situations (IEEE, 2019).
Impulsive Transitory and Oscillatory transient	Generally presented by switching events (Igual and Medrano, 2020).	It affects instantaneous dielectric breakdown or degradation in all types of equipment. It causes insulation failures in devices such as electrical machines, power transformers, capacitors, cables, and relays. In addition, causing tripping of the variable speed drives in the induction motors (Igual and Medrano, 2020).
Voltage imbalance	Generated by unbalanced loads in the polyphase MSG, as well as by anomalies in the capacitor banks connected to the microgrid (Falahi et al., 2013).	Causes heating in induction motors and an unbalance in line currents in MSG (Falahi et al., 2013).

the most challenging and dangerous. The attackers penetrate the information network without changing the structure of the MSG, and the controllers or structure operators are unaware of it (Chlela et al., 2016).

- Attacks on data confidentiality: This type of attack does not intervene in the operation of the MSG, unlike the previous two. It is essential to maintain specific confidentiality policies because data must be protected against access and understanding by unauthorized parties. Unauthorized people usually use this information to retrieve user information, such as identity or electricity consumption (Rana and Abdelhadi, 2020).

Table 6 shows smart algorithms in artificial intelligence for communication and security in a micro smart grid.

Table 4: Smart algorithms for power quality.

Paper	Contribution	Techniques Used	Key features
Power Quality Profile Enhancement of Utility Connected Microgrid System Using ANFIS-UPQC (Senthil Kumar et al., 2015).	Optimizing the Unified Power Quality Conditioner (UPQC) device and developing an evolutionary strategy.	Neuro-fuzzy inference system (ANFIS).	Evolutionary adaptive strategy to face the challenge of scalability in the architecture of an electrical microgrid. The authors face the challenge of harmonics and amplitude disturbances such as Sag and Swell.
A hybrid gravitational search and pattern search algorithm for tuning damping controller parameters for a unified power flow controller-A comparative approach (Khadanga and Satapathy, 2018).	Optimal Tuning of a Unified Power Flow Controller (UPFC).	A Hybrid Gravitational Search Algorithm and Pattern Search Algorithm (GSA - PS).	Optimize disturbance compensation systems and design an evolutionary strategy. The authors face the challenge of harmonics, amplitude disturbances such as Sag and Swell, Flicker, Impulsive Transient, and Oscillatory transient.
Enhancing Power Quality in Microgrids With a New Online Control Strategy for DSTATCOM Using Reinforcement Learning Algorithm (Bagheri et al., 2018).	A strategy for optimal control of Distribution Static Compensator (DSTATCOM).	Reinforcement Learning (RL).	Designed to compensate for reactive power, harmonics, and unbalanced load current in a microgrid using voltage and current parameters. The authors work with Flicker, Impulsive Transient, and Oscillatory transient disturbances and disturbances such as Sag and Swell.
Optimal Voltage and Frequency Control of an Islanded Microgrid using Grasshopper Optimization Algorithm (Jumani et al., 2018).	Optimize PI controller parameters.	Grasshopper optimization algorithm.	The methodology compensates for minimal voltage and frequency overshoot with minimal output current and total harmonic distortion (THD). Mitigated disturbances are based on amplitude, such as Sag and Swell.
Salp Swarm Optimization Algorithm-Based Controller for Dynamic Response and Power Quality Enhancement of an Islanded Microgrid (Jumani et al., 2019).	Controller for optimization in a PID control.	Salp Swarm optimization algorithms.	Proper control architecture of islanded MG is essential to control the voltage and frequency, including the power quality and optimal transient response during different operating conditions. The authors work with Flicker, Impulsive Transient, and Oscillatory transient disturbances and disturbances such as Sag and Swell.
MIMO Adaptive Bspline-Based Wavelet NeuroFuzzy Control for Multi-Type FACTS (Badar et al., 2020).	Multiple-input-multiple-output NeuroFuzzy control for multi-type Flexible AC Transmission Systems (FACTS).	Spline-based neural network (NN).	The application of this controller to provide damping signals to various FACTS controllers like Static Synchronous Series Compensator (SSSC) and Static Synchronous Compensator (STATCOM) can effectively enhance the dynamic stability of the system. On the other hand, the disturbances that are mitigated are based on amplitude, such as Sag and Swell, Flicker, Impulsive Transient, and Oscillatory transient.
Artificial intelligence-based grid-connected inverters for power quality improvement in smart grid applications (Das et al., 2021).	Advanced control strategy through hybrid shunt filters (SHF) for compensation of disturbances in amplitude with different types of loads.	Adaptive Fuzzy-Neural-Network Control (AFNN).	Reduces harmonics within the limit below 5 % THD. The authors work with frequency disturbances such as Flicker, Impulsive Transient, and Oscillatory transient.
A Smart Microgrid System with Artificial Intelligence for Power-Sharing and Power Quality Improvement (Nair et al., 2022).	An artificial intelligence-based Icosϕ control algorithm for power sharing and power quality.	Fuzzy logic controller.	The authors face the challenge of harmonics, amplitude disturbances such as Sag and Swell, Flicker, Impulsive Transient, and Oscillatory transient.
Power Quality Issues Mitigation in an AC Microgrid Through Bayesian Regularization Algorithm-Trained Artificial Neural Network (Choudhury et al., 2022).	ANN-based DSTATCOM controller.	Bayesian Regularization Algorithm-Trained Artificial Neural Network.	The authors face the challenge of harmonics, amplitude disturbances such as Sag and Swell, Flicker.
Persistent Voltage Profiling of a Wind Energy-Driven Islanded Microgrid with Novel Neuro-fuzzy Controlled Electric Spring (Mohanty et al., 2023).	Neuro-fuzzy Controlled Electric Spring.	Neural network-based fuzzy.	Regarding stability and performance parameters such as settling time, rise time, and maximum overshoot. The authors work with Flicker, Impulsive Transient, and Oscillatory transient disturbances and disturbances such as Sag and Swell.

Table 5: Smart algorithms for energy storage systems.

Paper	Contribution	Techniques Used	Key features
Multiobjective Optimal Sizing for Battery Storage of PV-Based Microgrid with Demand Response (Zhou et al., 2016).	Multiobjective model for electrical energy management, balancing energy generation and demand.	Genetic algorithm II (NSGA-II).	Constraint conditions such as power supply and demand balance, lateral electricity price elasticity, PV consumption rate, and annual net profit were considered.
A hybrid energy management and battery size optimization for standalone microgrids: A case study for Flinders Island, Australia (El-Bidairi et al., 2018).	The synergy of two techniques for battery size and power management.	Fuzzy logic and gray wolf optimization (FL-GWO).	Decreases the energy loss by 14.13 % and 24.15 %.
Energy storage capacity optimization for autonomy microgrid considering CHP and EV scheduling (Liu et al., 2018a).	The methodology is based on the Life Cycle Cost Theory (LCC), which includes the cost of construction, maintenance of operation, the profits from recycling, the environmental cost, and compensation for energy shortages.	Particle Swarm Optimization (PSO).	The results show a saving of 30 % of energy due to the administration of the dimensioning of the storage systems through the evolutionary algorithm.
Grey Wolf Optimization-Based Optimum Energy-Management and Battery-Sizing Method for Grid-Connected Microgrids (Nimma et al., 2018).	Development of a model for economic optimization.	Gray wolf optimization (GWO).	Minimizes microgrid operating costs by 33.185 %.
Optimal sizing of PV/wind/diesel hybrid microgrid system using multiobjective self-adaptive differential evolution algorithm (Ramli et al., 2018).	Model for Optimal sizing of PV/wind/diesel hybrid system with battery storage.	Multiobjective Self-Adaptive Differential Evolution (MOSaDE) algorithm.	Three case studies are proposed for the implementation of the strategy, showing not only sizing optimization but also a considerable percentage of energy reduction.
HYRES: A Multiobjective Optimization Tool for Proper Configuration of Renewable Hybrid Energy Systems (Donado et al., 2019).	Multiobjective optimization using genetic algorithms (GA).	Genetic Algorithm (GA).	The model addresses the challenges of reliability, location, power demand, power generation, and scalability.
Optimal sizing of hybrid renewable energy system via artificial immune system under frequency stability constraints (Hafez et al., 2019).	Dimensioning methodology for generators and storage systems in microgrids with renewable generators.	Artificial immune system (AIS).	Confront the scalability and fluctuating nature of microgrids.
Multiobjective Sizing Optimization of Hybrid Renewable Energy Microgrid in a Standalone Marine Context (Zhu et al., 2021).	A tri-objective sizing optimization method is proposed, comprehensively considering the economy, reliability, and energy utilization indexes.	Multiobjective Gray Wolf Optimizer based on Halton sequence and social motivation strategy (HSMGWO).	The annual operation of the system is simulated for the tests with the sizing optimization algorithm. Presenting significant energy savings in the different case studies.
Analyzing Optimal Battery Sizing in Microgrids Based on the Feature Selection and Machine Learning Approaches (Khan et al., 2022).	The optimal size of the battery for microgrids in terms of battery autonomy. In the considered dataset, each instance comprises 40 attributes of the battery.	Support Vector Regression (SVR).	the highest performance with a Spearman's rank-ordered correlation constant of 0.9756, linear correlation constant of 0.9452, Kendall correlation constant of 0.8488, and root mean squared error of 0.0525.

An Improved Arithmetic Optimization Algorithm for the design of a microgrid with energy storage system: Case study of El Kharga Oasis, Egypt (Kharrich et al., 2022).	The objective function is minimizing the total net present cost, including all expenses during the project lifetime; the optimization respects other technical and ecologic aspects.	Arithmetic Optimization Algorithm (AOA) using the leading Aquila Optimizer (AO) operators.	The real case study is applied in a new hybrid renewable energy system (HRES) composed of PV, wind turbine, diesel generator, and battery system.
An efficient data-driven optimal sizing framework for photovoltaics-battery-based electric vehicle charging microgrid (Wei et al., 2022).	Fast-speed and accurate determination of MG sizes, considering non-linear battery degradation and optimal power dispatch under variant EV charging profiles.	Artificial Neural networks (ANN).	Projects with poor revenue will become profitable when the ESS price and PV price are below 154$/kWh and 615 $/kW, and all the studied cases are worth the investment with the ESS price lower than 77 $/kWh.
Optimal sizing design and integrated cost-benefit assessment of standalone microgrid system with different energy storage employing chameleon swarm algorithm: A rural case in Northeast China (Zhou and Xu, 2023).	Optimal component sizing is determined based on the actual local hourly meteorological data and load demand.	Chameleon swarm algorithm (CSA).	The results of the simulation experiments under the benchmark scenario reveal the PV/WT/Tid/Bat system.

9. Analysis and discussions

Table 7 shows essential points evaluated to determine the panorama of artificial intelligence in electrical microgrids. The table presents points as a challenge to solve; possible solutions are shown in Tables 1, 2, 4, 5, 6, and 7. It also analyzes the challenges and potential solutions, showing strengths, opportunities, threats, and weaknesses. This table takes the basic elements for an intelligent electrical microgrid, energy management, monitoring electrical disturbances, control and mitigation of electrical disturbances, Energy storage systems, communication, and security systems.

There are many points to discuss about the evolution of the proposed articles and potential solutions. Many patterns are noted in scientific and technological fields within the studies. In the scientific field, super complex hybrid contributions are denoted where authors try to solve the problem and propose combinations of different algorithms, such as neural networks with genetic algorithms or some strategy based on evolutionary computation. The author takes methodologies from machine learning, evolutionary computation, and deep learning, mixing all these methodologies to propose a novel methodology. These innovative methodologies are intended to be multiobjective, to provide a solution to some retro within electrical microgrids, such as monitoring electrical disturbances, and simultaneously optimize the parameters and hyperparameters of artificial intelligence, such as learning rate, layers and neurons in neural networks, Etc. This methodology could be impractical due to excessive computational consumption and slow response time, and implementing it in real-time or embedded systems could be a problem.

The technological field has two critical aspects: the evolution of electrical and electronic devices, communication protocols, and data security methodology. When implementing them in this type of energy-generating architecture, the development of this type of scheme is observed, as discussed in section II. However, the other important aspect is the technological limitation regarding embedded devices, computational devices, and sensors, among other elements used for this type of research. There is often a need for improvement in which algorithms that work exceptionally well in real-life simulations have severe problems with precision and response time. In addition to having this problem of technological limitations, the economic limitation can also be an obstacle to development in this type of research. The adequate instrumentation to propose, develop research, and obtain data for model training, among other tasks needing specific instrumentation, must be revised, especially for researchers starting research lines in this area.

10. Conclusions

This paper presents a study, analysis, and summary of artificial intelligence's role in recent years to show researchers the challenges, opportunities, threats, and weaknesses that artificial intelligence faces in micro smart grids (MSG). In general, at the beginning of the paper, it was shown that although traditional and smart microgrids had specific differences, at the end of it all, both have the general objective in common, which is to generate energy through different types of distributed generators and distribute this generated energy to various users consume it for different purposes. Artificial intelligence is applicable in both generation and distribution schemes. However, the MSG has areas of study and a higher complexity level than the traditional ones. Due to the different systems that make it up, the technological evolution, and the electrical and electronic devices called consumers.

This study shows the challenges due to the rapid evolution of technologies that require certain quality, quantity,

Table 6: Smart Algorithms for communication systems and security systems.

Paper	Contribution	Techniques Used	Key features
Securing Metering Infrastructure of Smart Grid: A Machine Learning and Localization Based Key Management Approach (Parvez et al., 2016).	Methodology for authentication and identification of energy consumption metering systems.	k-nearest neighbors (KNN).	Identification and location system for smart meters with bidirectional communication.
Preventive Control Policy Construction in Active Distribution Network of Cyber-Physical System with Reinforcement Learning (Sun et al., 2020).	Methodology to detect intrusions in advanced metering infrastruc	Deep learning.	The model comprises CNN and LSTM components connected in a cross-layer; the CNN component recognizes regional features to obtain global features, while the LSTM component obtains periodic features by memory function.
Relational Deep Reinforcement Learning for Routing in Wireless Networks (Manfredi et al., 2021).	Distributed routing strategy based on deep reinforcement learning that generalizes to diverse traffic patterns, congestion levels, network connectivity, and link dynamics.	Deep Reinforcement Learning.	The algorithm overcomes the shortest path and back pressure routing concerning packets delivered and delay per packet.
A deep learning-based secured energy management framework within a smart island (Chang et al., 2021).	the aim of enabling attack detection in DC smart MG.	Deep learning and FFT.	The most crucial factor of the proposed detection plan can be that it can detect cyber-attacks with great precision.
Stochastic energy management and scheduling of microgrids in the correlated environment: A deep learning-oriented approach (Cheng et al., 2021).	This paper proposes a secured stochastic energy management scheme for both grid-connected and islanded hybrid AC-DC MGs (HMGs), considering renewable energy sources (RESs), plug-in hybrid electric vehicles (PHEVs), and energy storage devices (ESs).	A deep learning-based intrusion detection system (IDS) based on the long short-term memory.	The proposed scheme's performance is evaluated using the IEEE 33 bus test system for both operation modes.
Intelligent anomaly identification in cyber-physical inverter-based systems (Khan et al., 2021).	Multi-class support vector machine (MSVM) detected 80 % of the anomalies.	Support vector machine.	The effects of cyber anomalies such as false data injection and denial of service attacks are considered in addition to power system faults.
A Secured Advanced Management Architecture in Peer-to-Peer Energy Trading for Multi-Microgrid in the Stochastic Environment (Mohamed et al., 2021).	Modified intelligent priority selection-based reinforcement learning method (IPS-RL) effective.	Intelligent Priority Selection based Reinforcement Learning (IPS-RL), hybrid methodology with the help of reinforcement learning.	The proposal shows better performance than other methodologies such as support vector machine (SVM), reinforcement learning (RL), particle swarm optimization (PSO)-RL, and genetic algorithm (GA)-RL. Detect and stop malicious attacks in the shortest possible time for effective power trading based on peer-to-peer structure.
Codesign of FDI Attacks Detection, Isolation, and Mitigation for Complex Microgrid Systems: An HBF-NN-Based Approach (Tian et al., 2022).	Design an intelligent false data injection (FDI) attack detection, isolation, and mitigation scheme for complex microgrid systems with electric vehicles (EVs).	Hyper basis function neural network (HBF-NN).	One simulation provides tangible evidence of the feasibility and superiority of the proposed FDI attacks detection, isolation, and mitigation methodology.
Data-Driven Cyber-Attack Detection of Intelligent Attacks in Islanded DC Microgrids (Wan and Dragicevic, 2023).	A data-driven cyber-attack detection method for islanded DC microgrids is proposed.	Reinforcement learning (RL) algorithm and neural network.	The reinforcement learning (RL) algorithm emulates the actions of such an intelligent attacker, who exploits the vulnerability of index-based cyber-attack detection methods, such as discordant detection algorithms.

Table 7: Analysis and comparison of smart strategies in different areas of a Micro Smart Grid.

Elements of smart microgrids	Challenge	Potential solutions	Strengths and opportunities	Threats and weaknesses
Energy management	The balance between energy generation and consumption.	Neural networks, deep neural networks, evolutionary computation.	Development of new proposals in evolutionary computation for multiobjective systems.	Technological limitations that affect the accuracy of the methodology and also slow response time, affecting the performance of the energy management system.
Monitoring electrical disturbances	Monitoring and analysis of electrical disturbances.	Support Vector Machine, neural networks, deep neural networks, random forest, naïve Bayes.	Contributions to the development of algorithms for feature extraction that adapt to signals with stochastic intrinsic features.	Stochastic behavior of electrical disturbances.
Control and mitigation of electrical disturbances	Compensation for electrical disturbances.	Support Vector Machine, neural networks, deep neural networks, random forest, naïve bayes, evolutionary computing.	Optimal and intelligent disturbance control, giving greater importance to disturbances that affect the architecture of the energy generation and consumption scheme.	Scalability of the power generation scheme and stochastic behavior of electrical disturbances.
Energy storage systems	Storage system sizing optimization.	Neural networks, deep neural networks, evolutionary computation.	Development of new proposals in evolutionary computation for multiobjective systems.	Technological limitations that affect the accuracy of the methodology and also slow response time, affecting the performance of the energy management system.
Communication systems	Interoperability in the scheme that is integral, trustworthy, and discreet.	Support Vector Machine, neural networks, deep neural networks, random forest, naïve Bayes.	Speed up the communication methodology and which could be replicable for other areas where wireless communication protocols are required.	Technological limitations that affect communication latency.
Security systems	Provide the power generator scheme with intrinsic data security characteristics.	Support Vector Machine, neural networks, deep neural networks, random forest, naïve Bayes.	Development of strategies that provide data integrity, reliability, and discretion. On the other hand, it could apply to other areas where wireless communication protocols are required.	Technological limitations that do not support encryption methodologies due to the long processing time, which affects the response time and reliability of the network.

and energy characteristics. Artificial intelligence smart micro girds have various trends, challenges, weaknesses, and problems. However, artificial intelligence adapts naturally to solve different management problems, monitoring electrical power quality, compensation of functions, and optimizing the storage system.

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