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ARTIFICIAL INTELLIGENCE APPLIED TO INTELLIGENT LOAD DISPATCH IN PHOTOVOLTAIC SYSTEMS: A SYSTEMATIC REVIEW WITH APPLIED ANALYSIS

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Abstract: The increasing penetration of photovoltaic systems into the energy matrix has intensified challenges related to efficient energy management, particularly due to generation intermittency and variability in electrical demand. In this context, intelligent load dispatch plays a fundamental role in decision-making regarding local consumption of generated energy, storage in battery systems, or injection of surplus energy into the electrical grid. This article investigates the application of Artificial Intelligence techniques to load dispatch in photovoltaic systems, focusing on adaptive and data-driven decision strategies. The study is conducted through a systematic literature review, covering recent publications that employ machine learning algorithms, reinforcement learning, artificial neural networks, and fuzzy logic for energy management. The adopted methodology involves rigorous selection of studies, classification of the identified approaches, and comparative analysis of methods considering system architectures and energy performance metrics. As an additional contribution, a conceptual framework for intelligent load dispatch is proposed, integrating photovoltaic generation, loads, energy storage systems, and artificial intelligence algorithms, aiming to optimize energy efficiency and enhance operational reliability. The results indicate that artificial intelligence-based approaches outperform traditional load dispatch methods.

Keywords: Artificial Intelligence. Intelligent Load Dispatch. Photovoltaic Systems. Energy Management. Systematic Review.

INTRODUCTION

The expansion of photovoltaic (PV) systems in residential, commercial, and microgrid applications has intensified energy management challenges, primarily due to the intermittency of solar generation and the temporal mismatch between production and consumption. According to Alankrita *et al.* (2022), in grid-connected PV systems with battery energy storage, inadequate dispatch decisions can compromise overall system efficiency and accelerate storage device degradation processes. Recent studies also indicate that this issue becomes more critical as the share of renewable sources grows within the power matrix (PERERA; KAMALARUBAN, 2021).

Historically, load dispatch in photovoltaic systems was conducted using deterministic strategies based on fixed rules, such as state-of-charge thresholds, static self--consumption priorities, and simple peak shaving policies. According to Mateo Romero *et al.* (2022), such approaches show limited performance in dynamic scenarios where generation, demand, and tariffs vary continuously over time. Similar findings are reported in recent review studies, which highlight the difficulty of these methods in dealing with complex and tightly coupled energy systems (KUMAR *et al.*, 2024).

With the advancement of energy systems digitalization and the increasing availability of real-time data, Artificial Intelligence (AI) techniques have been widely investigated as alternatives for load dispatch in photovoltaic systems. These techniques include machine learning, artificial neural networks, reinforcement learning, and fuzzy logic, applied to both the forecasting of energy variables and operational decision-making. According to Mateo Romero *et al.* (2022), Artificial Intelligence has demonstrated a high capacity to handle the non-linearities and uncertainties inherent in photovoltaic systems, although challenges related to data quality and computational complexity still remain.

In the specific scope of load dispatch in systems composed of photovoltaic generation, battery storage, and grid connection, reinforcement learning stands out by formulating the problem as a sequential decision process. Authors such as Xu *et al.* (2023) demonstrate that this approach allows for learning control policies capable of reducing operational costs and increasing energy self-consumption in grid-connected residential photovoltaic systems. In a complementary study, Kang *et al.* (2024) show that reinforcement learning-based models exhibit superior performance compared to conventional strategies in battery storage system scheduling, especially in environments subject to high variability (KANG *et al.*, 2024).

In addition to reinforcement learning--based approaches, fuzzy logic techniques remain relevant due to their interpretability and ease of implementation in control architectures. Alankrita *et al.* (2022) propose an energy management system based on fuzzy logic for hybrid grid-connected photovoltaic systems, directing the power flow between the battery and the grid to smooth fluctuations and improve the utilization of available energy resources. Other studies reinforce that this type of approach is particularly useful when well-defined heuristic rules can be incorporated into the decision-making process (ALANKRITA *et al.*, 2022).

Despite the advances observed in recent literature, there is still a significant dispersion of approaches, hypotheses, and performance metrics adopted in studies. Metrics such as operational cost, self-consumption rate, peak demand reduction, battery degradation, and system reliability are frequently evaluated in isolation, making direct comparisons between methods difficult. This scenario reinforces the need for a critical consolidation of available evidence, focusing not only on the algorithms used but also on how these techniques are effectively applied to load dispatch[1] in photovoltaic systems. Figure 1, authored by the researcher, illustrates the general decision structure in intelligent load dispatch for photovoltaic systems, highlighting the main energy flows and the role of artificial intelligence in the decision-making process.

1 In this work, load dispatch refers to the decision-making process of allocating energy flow between consumption, storage, and grid injection, distinguishing itself from energy management, which involves planning and supervision, and from control, which concerns the direct execution of commands on physical devices.

In light of this, this article aims to conduct a systematic literature review on the application of Artificial Intelligence to intelligent load dispatch in photovoltaic systems, with an emphasis on decisions related to local consumption of generated energy, battery system storage, and power injection into the grid. Additionally, an applied analysis of the main architectures and strategies found in recent literature is presented, culminating in the proposal of a conceptual intelligent dispatch framework that integrates photovoltaic generation, loads, storage systems, the power grid, and Artificial Intelligence algorithms, oriented toward energy efficiency and operational reliability.

THEORETICAL FOUNDATION

This theoretical foundation aims to underpin the core concepts, technologies, and approaches related to intelligent load dispatch in photovoltaic systems, establishing

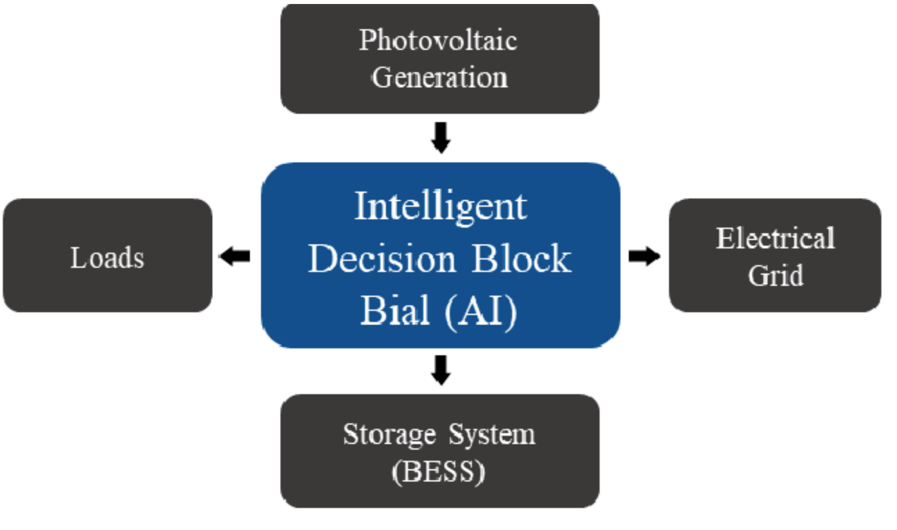

Figure 1. General decision structure in intelligent load dispatch for photovoltaic systems

Source: Developed by the authors (2026).

the conceptual basis required for the analysis developed in this article. Initially, the characteristics of photovoltaic generation and the challenges associated with source intermittency are discussed. Next, the concepts of load dispatch and the role of energy storage systems within the photovoltaic context are addressed. Subsequently, the fundamentals of artificial intelligence applied to energy systems are presented, emphasizing the techniques most frequently employed in recent literature. Finally, the primary artificial intelligence-based approaches applied specifically to load dispatch in photovoltaic systems are analyzed, providing a critical synthesis of the state of the art and identifying research gaps.

Photovoltaic Systems and Generation Intermittency

Energy generation through photovoltaic systems has shown significant growth in recent decades, driven by declining module costs, technological advancements in inverters, and public policies incentivizing both distributed and centralized generation. According to recent reports from the International Renewable Energy Agency, solar photovoltaic energy ranks among the renewable sources with the highest global expansion rates, playing a strategic role in the decarbonization of the power sector and the diversification of the energy matrix (IRENA, 2023).

Despite this progress, photovoltaic systems possess intrinsic characteristics that impose significant operational challenges. The most prominent of these is generation intermittency, resulting from a direct dependence on solar irradiance, which varies according to climatic, geographic, and temporal factors. According to the REN21 (2023) report, short- and long-term variations in irradiance result in significant fluctuations in power output, affecting energy production predictability and the stability of electrical systems with high penetration of renewable sources (REN21, 2023).

Authors such as Lund *et al.* (2021) highlight that, unlike conventional dispatchable sources, photovoltaic generation has limited capacity for direct control over its instantaneous production, which complicates real-time balancing between supply and demand. Recent studies reinforce that this characteristic becomes particularly critical in scenarios with high photovoltaic penetration, where generation variability can cause overloads, reverse power flows, and additional challenges to the operation of distribution networks (LUND *et al.*, 2021).

In addition to variations associated with the daily cycle and meteorological conditions, the intermittency of photovoltaic generation also manifests across distinct temporal scales, ranging from rapid fluctuations caused by transient shading and cloud cover to seasonal variations related to solar tilt and regional climate regimes. The variability illustrated in Figure 2, authored by the researchers, highlights the need for mechanisms capable of mitigating the impacts of intermittency, reinforcing the importance of dispatch strategies and energy management in photovoltaic systems.

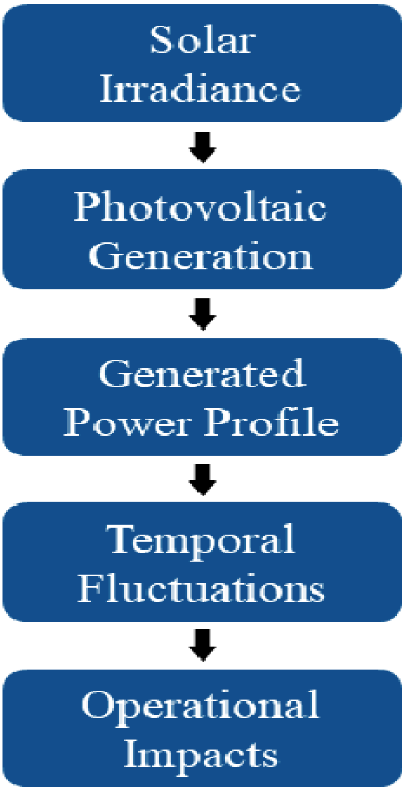

Figure 2. Temporal variability of photovoltaic generation and operational impacts

Source: Developed by the authors (2026).

According to recent studies in specialized literature, these fluctuations directly impact the power quality provided, system reliability, and the overall efficiency of photovoltaic operation (CHATZIGEORGIOU *et al.,* 2024).

In this context, the literature points out that simply expanding the installed capacity of photovoltaic systems is not enough to ensure adequate electrical system performance. According to Hossain *et al.* (2022), it is fundamental to adopt advanced management and control strategies capable of dealing with generation variability and mitigating its operational impacts, especially in grid-connected systems and microgrids with a high penetration of renewable sources (HOSSAIN *et al.,* 2022).

Recent studies also show that the intermittency of photovoltaic generation intensifies the time decoupling between production and consumption, reinforcing the need for mechanisms that allow for greater operational flexibility. According to Morales *et al.* (2020), this decoupling is one of the main drivers for integrating energy storage systems and developing intelligent load dispatch strategies capable of adapting system operation to instantaneous generation and demand conditions (MORALES *et al.,* 2020).

Thus, the inherent intermittency of photovoltaic systems is a central factor in the motivation to develop advanced dispatch and energy management methods. Recent literature converges in indicating that mitigating the effects of this variability requires approaches that combine operational flexibility, adaptability, and decision-making based on multiple variables, paving the way for the application of artificial intelligence techniques in the context of intelligent load dispatch in photovoltaic systems.

Load Dispatch in Energy Systems

Load dispatch is a central element in the operation of modern energy systems, especially those integrating intermittent renewable sources, storage systems, and grid connections. In general, dispatch refers to the decision-making process responsible for determining how available energy will be allocated among different alternatives such as local consumption, storage, or export to the grid, while considering technical, economic, and operational constraints. According to Lund *et al.* (2021), energy dispatch plays a strategic role in systems with high generation variability, as it directly influences efficiency, reliability, and operational costs.

In conventional electrical systems, dispatch has historically been associated with the scheduling of dispatchable plants, such as thermoelectric and hydroelectric plants, whose generation levels can be adjusted according to demand. However, with the increasing integration of non-dispatchable renewable sources, such as photovoltaic and wind generation, the concept of dispatch incorporates new dimensions, shifting the focus from generation control to power flow management between loads, storage, and the power grid (LUND *et al.,* 2021).

In the context of photovoltaic systems, load dispatch differs from related concepts such as energy management and real-time control. Energy management involves a broader set of activities, including planning, forecasting, defining operational policies, and system supervision over time. Control, on the other hand, refers to the direct execution of commands on physical devices, such as inverters and converters. Dispatch, in turn, sits at an intermediate level, acting as the decision-making mechanism that translates system information into specific operational actions. According to Chatzigeorgiou *et al.* (2024), this conceptual distinction is fundamental for the correct development and evaluation of operation strategies in complex energy systems.

Traditionally, load dispatch in photovoltaic systems has been implemented through fixed rule-based strategies, defined by battery state-of-charge (SoC) thresholds, rigid self-consumption priorities, or simple policies for injecting surplus into the grid. Although these strategies offer implementation simplicity and low computational cost, several studies point out their limitations in dynamic and uncertain scenarios. Results reported in the literature indicate that deterministic methods tend to exhibit suboptimal performance when subjected to rapid variations in generation and demand, in addition to failing to adequately consider multiple simultaneous objectives, such as cost, storage degradation, and power quality (HOSSAIN *et al.,* 2022).

With the advancement of smart grids and the increased availability of real-time data, more sophisticated dispatch approaches have emerged, often termed intelligent load dispatch. These approaches incorporate information from sensors, generation and consumption forecasts, price signals, and operational constraints, allowing for more adaptive and contextualized decisions. Authors such as Perera and Kamalaruban (2021) highlight that intelligent dispatch represents a natural evolution of traditional methods by enabling the explicit consideration of uncertainty and the sequential nature of energy decisions.

In the specific case of photovoltaic systems with storage, intelligent dispatch assumes even greater relevance, since inadequate decisions can directly impact battery life and the system's economic viability. Recent studies demonstrate that advanced dispatch strategies can significantly improve indicators such as self-consumption rates, peak demand reduction, and total operating costs when compared to approaches based exclusively on fixed rules (KANG *et al.,* 2024).

Thus, it is observed that load dispatch has evolved from a simple deterministic mechanism to a complex decision-making process, heavily dependent on data, forecasts, and decision models. This evolution creates the necessary context for applying artificial intelligence techniques, which will be discussed in the subsequent sections, especially regarding intelligent load dispatch in photovoltaic systems. The main distinctions between traditional load dispatch strategies and intelligent approaches are summarized in Table 1.

Energy Storage Systems in Photovoltaic Systems

Energy storage systems play a fundamental role in mitigating the effects of the intermittency inherent to photovoltaic generation by allowing for time decoupling between production and consumption. In grid-connected photovoltaic systems or microgrids, storage enables the absorption of generation surpluses and their subsequent use during periods of low production or high demand, contributing to greater operational flexibility. According to Chatzigeorgiou *et al.* (2024), the integration of photovoltaic systems with storage is one of the primary enablers for the efficient operation of energy systems with high penetration of renewable sources.

Among the various available storage technologies, electrochemical batteries, particularly lithium-ion batteries, have established themselves as the predominant solution in distributed and small-to-medium-scale photovoltaic applications. This predominance stems from characteristics such as high energy density, high charge and discharge efficiency, fast dynamic response, and the progressive reduction of production costs. According to Zakeri and Syri (2020), lithium-ion batteries present favorable technical and economic performance when compared to other storage technologies in stationary applications associated with renewable generation. The integration between photovoltaic generation, storage systems, and the power grid can be conceptually represented as illustrated in Figure 3.

Despite their benefits, storage systems impose relevant operational constraints that directly influence load dispatch strategies. Parameters such as state of charge, depth of discharge, power limits, and conversion efficiency must be considered in the decision-making process to avoid compromising battery life and system reliability. Recent studies indicate that frequent charging and deep discharge cycles accelerate degradation mechanisms, reducing the useful storage capacity over time (SCHMIDT *et al.*, 2021).

In the context of load dispatch, the presence of storage transforms an essentially reactive problem into a strategic decision problem. According to Wu *et al.* (2022), inadequate decisions regarding when to charge or discharge batteries can result in increased operational costs, underutilization of generated photovoltaic energy, and a reduction in the economic return on investment. Thus, storage should not be treated merely as a passive element of the system, but as an active resource whose operation must be optimized.

Recent literature highlights that the efficient integration of photovoltaic systems and storage requires control and dispatch strategies capable of simultaneously handling multiple objectives, such as maximizing self-consumption, reducing peak demand, minimizing costs, and preserving battery life. Authors such as Liu *et al.* (2025) demonstrate that traditional rule-based approaches show limited performance when faced with this set of conflicting objectives, reinforcing the need for more adaptive and intelligent methods (LIU *et al.*, 2025).

Criterion	Classical Strategies	Intelligent Dispatch
Decision basis	Fixed rules	Data and learning
Adaptability	Low	High
Uncertainty handling	Limited	Explicit
Multiple objectives	Restricted	Multiple
Computational complexity	Low	Moderate to high

Table 1. Comparison between classical and intelligent load dispatch strategies

Source: Developed by the authors (2026).

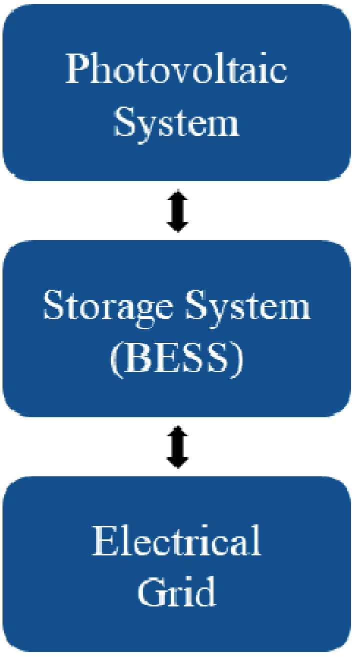

Figure 3. Integration between photovoltaic system, battery storage, and the power grid

Source: Developed by the authors (2026).

Furthermore, the integration of photovoltaic systems with storage increases the complexity of the energy system, as dispatch decisions begin to depend on additional variables and their dynamic interactions over time. Recent studies point out that this growing complexity makes the problem particularly suitable for the application of artificial intelligence techniques, which are capable of exploring historical patterns and real-time information to support more efficient decisions (HUANG *et al.,* 2025).

Thus, it is observed that storage systems constitute a central element in enabling intelligent load dispatch in photovoltaic systems. Their correct integration and operation directly influence the energetic, economic, and operational performance of the system, establishing the necessary link between photovoltaic generation variability and the flexibility required to meet demand. This observation paves the way for the discussion in subsequent sections regarding the use of artificial intelligence techniques as tools to support intelligent load dispatch.

Artificial Intelligence Applied to Energy Systems

The growing complexity of modern energy systems, characterized by the integration of intermittent renewable sources, storage systems, and multiple decision agents, has driven the adoption of advanced Artificial Intelligence (AI) techniques as support tools for energy planning, control, and dispatch. According to Perera and Kamalaruban (2021), AI offers an adequate framework for dealing with energy problems involving non-linearities, uncertainties, and sequential decisions, which are recurring aspects in grid-connected photovoltaic systems.

In the energy context, Artificial Intelligence can be understood as a set of computational methods capable of extracting knowledge from data, learning patterns, and supporting decision-making processes adaptively. According to Lund *et al.* (2021), the application of AI techniques in energy systems has intensified as digitalization and real-time data availability become more accessible, especially in environments characterized by high operational variability.

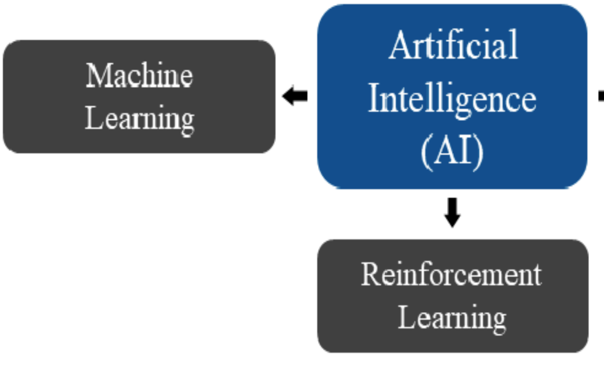

Figure 4. Main Artificial Intelligence approaches applied to energy systems

Among the main approaches employed in the field, supervised and unsupervised machine learning methods stand out, being widely used for tasks such as photovoltaic generation forecasting, load forecasting, and anomaly detection. Recent studies demonstrate that algorithms such as artificial neural networks, support vector machines, and random forests show superior performance compared to traditional statistical methods in energy forecasting problems, especially when large volumes of historical data are available (MATEO ROMERO *et al.,* 2022). The main Artificial Intelligence approaches applied to energy systems can be organized conceptually, as illustrated in Figure 4.

In addition to forecasting applications, reinforcement learning techniques[2] have gained prominence in control and energy dispatch problems. In this approach, the problem is formulated as a sequential decision process in which an agent interacts with the environment and learns action policies based on a reward function associated with the system's operational objectives. According to Perera and Kamalaruban (2021), reinforcement learning is particularly suitable for energy systems because it allows for the integrated incorporation of operational constraints, uncertainties, and multiple objectives.

Another relevant approach in the energy context is fuzzy logic, which is widely used in control systems due to its interpretability and ease of implementation. Fuzzy logic allows for the incorporation of expert knowledge through linguistic rules, making it especially useful in situations where the system behavior is known qualitatively but is difficult to model analytically. Studies indicate that fuzzy controllers show satisfactory performance in photovoltaic systems with storage, particularly in energy management architectures based on adaptive rules (ALANKRITA *et al.,* 2022).

Thus, it is observed that Artificial Intelligence applied to energy systems is not restricted to a single technique or purpose, ranging from forecasting tasks to complex decision-making and control processes. This diversity of approaches provides the theoretical support necessary for applying AI to intelligent load dispatch in photovoltaic systems, a topic that will be explored in depth in the following section.

AI in Intelligent Load Dispatch in Photovoltaic Systems

The application of Artificial Intelligence techniques to intelligent load dispatch in photovoltaic systems has intensified in recent years, driven by the need to handle generation variability, the complexity introduced by storage systems, and the multiplicity of operational objectives. In this context, AI enables the transformation of load dispatch into an adaptive decision-making process capable of incorporating historical information, real-time data, and forecasts to optimize the allocation of generated energy. According to Perera and Kamalaruban (2021), this type of approach is particularly suitable for energy systems where sequential decisions and uncertainties are inherent.

A significant portion of recent literature employs machine learning techniques to support load dispatch, especially in architectures where photovoltaic generation and demand forecasting constitute a preliminary stage to the decision-making process.

2. Reinforcement learning is an Artificial Intelligence technique in which an agent learns action policies through interaction with the environment, aiming to maximize a reward function associated with the system's objectives.

According to Mateo Romero *et al.* (2022), algorithms such as artificial neural networks, random forests, and support vector machines are widely used to estimate energy variables, the results of which feed dispatch strategies based on optimization or adaptive rules. Although these approaches show good results in terms of predictive accuracy, several studies point out that their effectiveness depends heavily on the quality and representativeness of the available data.

Regarding the decision-making process itself, reinforcement learning stands out as one of the most investigated approaches for intelligent load dispatch in photovoltaic systems. In this line, the dispatch problem is formulated as a sequential decision process in which the agent learns action policies through interaction with the energy environment. Authors such as Xu *et al.* (2023) demonstrate that reinforcement learning methods can reduce operational costs and increase energy self-consumption in residential photovoltaic systems with storage when compared to traditional deterministic strategies. Similar results are reported in more recent studies that emphasize the ability of reinforcement learning to handle multiple objectives and operational constraints (KANG *et al.,* 2024).

At the same time, approaches based on fuzzy logic continue to be employed in load dispatch, especially in systems where expert knowledge can be translated into linguistic rules. According to Alankrita *et al.* (2022), fuzzy systems offer good interpretability and low computational cost, characteristics that make them attractive for real-time applications. However, the literature also points out limitations related to the scalability of these approaches and the difficulty of manually adjusting membership functions in highly dynamic scenarios. The conceptual architecture of intelligent load dispatch in photovoltaic systems, integrating different Artificial Intelligence techniques, is illustrated in Figure 5.

More recently, the emergence of hybrid models combining different Artificial Intelligence techniques has been observed, seeking to exploit the advantages of each approach. Studies indicate that the integration of machine learning for forecasting, reinforcement learning for decision-making, and fuzzy logic for interpretation and control can result in more robust and efficient dispatch systems. According to Huang et al. (2025), these hybrid architectures represent a promising trend in the context of intelligent load dispatch in photovoltaic systems, although challenges related to computational complexity and validation in real-world environments still exist.

Despite the observed advancements, the literature reveals a significant diversity of architectures, hypotheses, and evaluation metrics, making direct comparisons between studies difficult. Metrics such as operational cost, self-consumption rate, peak demand reduction, and impact on battery degradation are frequently analyzed in isolation. This scenario reinforces the need for a systematization of existing approaches, allowing for the identification of patterns, recurring limitations, and research gaps in the use of Artificial Intelligence for intelligent load dispatch in photovoltaic systems. Table 2 presents a synthesis of the main Artificial Intelligence approaches applied to load dispatch in photovoltaic systems.

Critical Synthesis of the Literature Review

The analysis of recent literature highlights that the increasing insertion of pho-

Approach	AI Technique	Primary Objective	System Type
Machine learning	ANN, RF, SVM	Forecasting	Grid-connected PV
Reinforcement learning	Q-learning, DQN	Optimal dispatch	PV + BESS
Fuzzy logic	Linguistic rules	Adaptive control	Hybrid PV
Hybrid models	ML + RL + Fuzzy	Robustness and efficiency	PV + BESS + Grid

Table 2. Synthesis of the main AI approaches applied to load dispatch in photovoltaic systems

Source: Developed by the authors (2026).

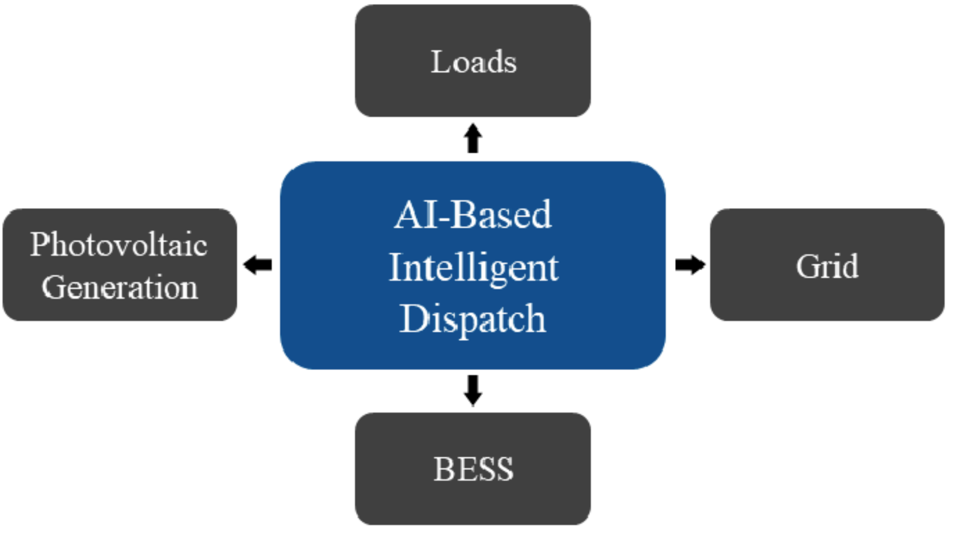

Figure 5. Conceptual architecture of intelligent load dispatch in photovoltaic systems

Source: Developed by the authors (2026).

tovoltaic systems into the electrical matrix has intensified the challenges associated with load dispatch, especially in scenarios characterized by high generation variability and the presence of storage systems. As discussed in previous sections, the intermittency inherent to photovoltaic generation imposes limitations on traditional operational strategies, requiring mechanisms capable of handling uncertainties and multiple operational objectives. In this context, load dispatch ceases to be a purely deterministic problem and begins to demand more flexible and adaptive approaches.

The analyzed studies indicate that classical dispatch strategies, based on fixed rules and predefined thresholds, show limited performance when faced with dynamic and highly coupled environments. Although these approaches are still widely used in commercial applications due to their simplicity and low computational cost, the literature converges in pointing out that such methods tend to result in suboptimal solutions, especially when simultaneously seeking to maximize self-consumption, reduce costs, and preserve the life cycle of storage systems (LUND *et al.*, 2021; HOSSAIN *et al.*, 2022).

On the other hand, the incorporation of Artificial Intelligence techniques into load dispatch has demonstrated significant potential to overcome the limitations of traditional methods. Machine learning approaches stand out primarily in photovoltaic generation and demand forecasting tasks, providing important data for decision-making. However, several authors emphasize that the effectiveness of these techniques depends heavily on the availability and quality of data, as well as the generalization capability of the models in scenarios different from those used during training (MATEO ROMERO *et al.*, 2022).

Regarding operational decision-making, reinforcement learning emerges as one of the most promising approaches, as it allows for the formulation of load dispatch as a sequential decision process. The literature points out that this characteristic makes reinforcement learning particularly suitable for photovoltaic systems with storage, where current decisions directly impact future system states. Despite the positive results reported, recent studies also highlight challenges related to training stability, the definition of the reward function, and the validation of these models in real-world environments (PERERA; KAMALARUBAN, 2021; XU *et al.*, 2023).

Fuzzy logic-based approaches remain relevant, especially in systems where interpretability and ease of implementation are priority requirements. The literature recognizes that fuzzy systems show good robustness in scenarios with uncertainty and allow for the direct incorporation of expert knowledge. However, their scalability and the need for manual adjustments of rules and membership functions are frequently cited as limitations in more complex and larger-scale applications (ALANKRITA *et al.*, 2022).

A recurring aspect identified in the literature is the growing trend toward adopting hybrid models, which combine different Artificial Intelligence techniques to exploit the complementary advantages of each approach. These models seek to integrate forecasting methods based on machine learning, decision strategies grounded in reinforcement learning, and interpretable control mechanisms such as fuzzy logic. Although this trend is widely recognized as promising, it is observed that many studies still focus on simulated environments, with a lack of more comprehensive experimental validations and practical feasibility analyses (HUANG *et al.,* 2025; KANG *et al.,* 2024).

In general, the critical synthesis of the theoretical framework reveals that, despite significant advances in the use of Artificial Intelligence for load dispatch in photovoltaic systems, important research gaps persist. Key among them are the need for standardized evaluation metrics, the explicit consideration of storage system degradation in the decision-making process, and the integration of these approaches into scalable architectures applicable to the real world. These gaps reinforce the relevance of studies that not only review the state of the art but also propose integrative conceptual frameworks capable of guiding the development of more efficient and sustainable solutions.

METHODOLOGY

The present study is characterized as a systematic literature review, employing a qualitative approach and a descriptive-analytical nature. Its objective is to identify, organize, and critically analyze recent research addressing the application of Artificial Intelligence techniques in intelligent load dispatch within photovoltaic systems. The choice of a systematic review is justified by the need to consolidate dispersed scientific evidence, identify trends, limitations, and research gaps, as well as establish a consistent theoretical basis for proposing conceptual frameworks applied to the energy context.

Data Sources and Scientific Databases

The collection of studies was conducted across scientific databases widely recognized for their relevance and impact in the fields of engineering and energy, including Scopus, Web of Science, IEEE Xplore, and ScienceDirect. These databases were selected because they host international journals with high impact factors and offer multidisciplinary coverage, encompassing research related to photovoltaic systems, energy storage, load dispatch, and Artificial Intelligence. The use of multiple databases contributed to expanding the search coverage and reducing biases associated with restricted indexing.

Search Strategy and Study Selection

The search strategy was structured based on the combination of terms related to photovoltaic generation, load dispatch, energy management, and Artificial Intelligence techniques, employing Boolean operators to maximize the scope of the results without compromising their relevance. The searches were conducted within the title, abstract, and keyword fields of the articles indexed in the selected databases. The complete search string used in this study is presented in the footnote below[3]. Only works published between 2020 and 2025 were considered to ensure the timeliness and adherence of the studies to the state of the art of the investigated topic.

Eligibility Criteria

The selection of studies followed predefined eligibility criteria, applied sequentially throughout the screening process. Peer-reviewed scientific articles that expli-

3. The search string used was: ("photovoltaic system" OR "solar PV") AND ("energy dispatch" OR "load dispatch" OR "energy management") AND ("artificial intelligence" OR "machine learning" OR "reinforcement learning" OR "fuzzy logic").

citly addressed the application of Artificial Intelligence techniques in the dispatch or energy management of photovoltaic systems, with or without the integration of energy storage systems, were included. Additionally, only studies written in English with full-text access were considered. Duplicate works, purely conceptual studies without a direct link to energy dispatch, articles not involving photovoltaic systems, and publications that did not present a technical application or discussion of the proposed approaches were excluded.

Screening and Analysis Procedures

The screening process for the studies occurred in successive stages. Initially, the records obtained from the database searches were compiled and submitted for the removal of duplicates. Subsequently, an analysis of titles and abstracts was performed to eliminate works not aligned with the research scope. The remaining articles were then fully evaluated, considering the established eligibility criteria, resulting in the final set of studies included in the review. This systematic approach ensured consistency and transparency in the selection of the analyzed material.

Data Synthesis and Organization

After defining the final set of studies, the extraction and organization of relevant information proceeded, including the type of system analyzed, the Artificial Intelligence technique employed, dispatch objectives, evaluation metrics, and main reported results. The studies were then classified according to the adopted approaches, enabling comparative analyses and the identification of recurring patterns, methodological convergences, and research gaps. This stage provides the foundation for the discussion presented in the Results and Discussion section, as well as the proposal of the conceptual framework for intelligent dispatch developed in this work. The methodological process adopted for the selection and analysis of the studies can be represented schematically, as illustrated in Figure 6.

RESULTS AND DISCUSSION

This section presents and discusses the main results obtained from the systematic literature review, focusing on the identification, organization, and analysis of Artificial Intelligence approaches applied to intelligent load dispatch in photovoltaic

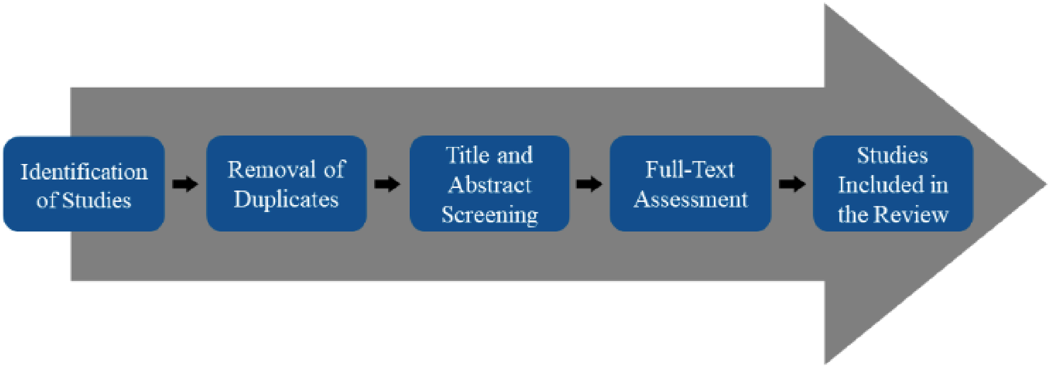

Figure 6. Flowchart of the systematic review methodological process

systems. Unlike experimental studies, the results discussed here do not refer to original empirical data, but to the critical synthesis of the findings reported in the analyzed studies, allowing for the identification of methodological patterns, predominant trends, recurring limitations, and future research opportunities.

The discussion is structured to integrate results and interpretation jointly, as per consolidated practice in systematic review articles in the field of applied engineering. Initially, the selected studies are classified according to the type of Artificial Intelligence approach employed and the application context. Subsequently, the main gains and limitations observed in the literature are discussed, culminating in the proposal of a conceptual framework for intelligent load dispatch in photovoltaic systems.

Classification of Identified Artificial Intelligence Approaches

The analysis of the selected studies reveals that the Artificial Intelligence approaches applied to load dispatch in photovoltaic systems can be grouped into three major categories: machine learning-based methods, reinforcement learning-grounded approaches, and fuzzy logic-based strategies, in addition to an emerging set of hybrid models that combine more than one technique. This classification allows for an understanding of how the literature has explored different AI paradigms to handle the problem of energy dispatch in environments characterized by variability, uncertainty, and multiple operational objectives.

Studies utilizing machine learning focus predominantly on photovoltaic generation and demand forecasting tasks, which serve as support for subsequent dispatch decisions. In these works, algorithms such as artificial neural networks, random forests, and support vector machines are employed to estimate energy variables with high accuracy, reducing the uncertainty associated with system operation. However, it is observed that, in most cases, the dispatch decision-making process remains based on rules or deterministic optimization, which limits the adaptive potential of these approaches when considered in isolation—a finding that aligns with recent literature analyses on AI applications in photovoltaic systems (MATEO ROMERO *et al.*, 2022).

Conversely, reinforcement learning-based studies treat load dispatch as a sequential decision problem, in which the agent learns action policies from continuous interaction with the energy environment. This class of approaches demonstrates a greater capacity to handle multiple simultaneous objectives, such as cost minimization, self-consumption maximization, and the preservation of battery life. The literature indicates that reinforcement learning methods tend to outperform traditional dispatch strategies in dynamic scenarios, although they require greater computational effort and additional care in defining the reward function and the training process.

Fuzzy logic-based approaches remain relevant, especially in applications that prioritize interpretability and implementation simplicity. These methods allow for the incorporation of expert knowledge through linguistic rules and are frequently used in small and medium-scale hybrid photovoltaic systems. However, the analyzed studies point out that the scalability of these approaches is limited, particularly as the number of variables and system constraints increases.

Finally, there is a growing trend in the literature toward hybrid models, which combine machine learning, reinforcement learning, and fuzzy logic techniques. These models seek to exploit the complementary advantages of each approach, resulting in more robust and flexible dispatch strategies. Although promising, such architectures are still mostly evaluated in simulated environments, highlighting the need for additional studies investigating their application in real-world contexts. The distribution of the analyzed studies according to the employed Artificial Intelligence approach is presented in Figure 7.

The values represent the relative distribution of the studies selected in the systematic review, grouped according to the predominant Artificial Intelligence approach adopted in each work. The synthesis of the analyzed studies, classified according to the Artificial Intelligence approach employed and the application context, is presented in Table 3.

Comparative Analysis of Artificial Intelligence Approaches

The comparative analysis of Artificial Intelligence approaches applied to load dispatch in photovoltaic systems highlights significant differences regarding the objectives addressed, computational complexity, and practical applicability. Although all analyzed techniques provide relevant contributions, their performances vary substantially depending on the energy system context, data availability, and the operational constraints considered.

Machine learning-based approaches stand out primarily for their high capacity to model non-linear relationships and produce accurate forecasts of photovoltaic generation and demand. These methods are particularly effective when large volumes of historical data are available, allowing for the reduction of uncertainties that impact the dispatch process. However, it is observed that, in many studies, machine learning acts as an auxiliary tool for dispatch, providing forecasts that feed external decision-making strategies. This separation between forecasting and decision-making limits the adaptive potential of these approaches when the system is subjected to abrupt variations or unforeseen conditions.

In turn, strategies grounded in reinforcement learning demonstrate greater integration between system state perception and decision-making. By formulating load dispatch as a sequential decision problem, these approaches allow for the direct optimization of objectives such as operational cost, self-consumption, and storage system degradation. The analyzed literature indicates that reinforcement learning methods tend to perform better in dynamic environments, especially in photovoltaic systems with batteries. However, this advantage is accompanied by higher computational complexity, longer training times, and sensitivity to the definition of the reward function—factors that can hinder their practical application in real-world systems, an aspect also highlighted in recent studies on reinforcement learning-based energy dispatch (XU *et al.*, 2023).

Fuzzy logic-based approaches are distinguished mainly by high interpretability and the ease of incorporating expert knowledge. These characteristics make fuzzy systems attractive for small and medium-scale applications, where decision transparency and implementation simplicity are relevant requirements. Nevertheless, the comparative analysis reveals that such methods have limitations in more complex scenarios,

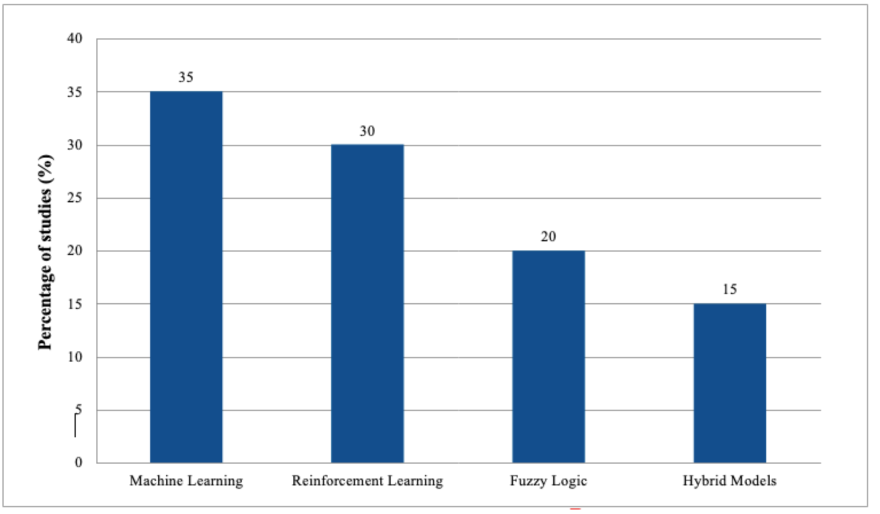

Figure 7. Distribution of analyzed studies by Artificial Intelligence approach

AI Approach	Main Objective	System Type	Frequency in Literature
Machine Learning	Forecasting	Grid-connected PV	High
Reinforcement Learning	Optimal Dispatch	PV + BESS	High
Fuzzy Logic	Adaptive Control	Hybrid PV	Moderate
Hybrid Models	Robustness and Flexibility	PV + BESS + Grid	Emerging

Table 3. Classification of the analyzed studies regarding the AI approach and the type of photovoltaic system

Source: Developed by the authors (2026).

Approach	Advantages	Limitations	Applicability
Machine Learning	High predictive accuracy	Indirect decision-making	High
Reinforcement Learning	Adaptive decision-making	High complexity	Moderate
Fuzzy Logic	Interpretability	Limited scalability	Moderate
Hybrid Models	Robustness	Complex implementation	Emerging

Table 4. Comparison between AI approaches applied to intelligent load dispatch

Source: Developed by the authors (2026).

where the number of variables, states, and constraints grows significantly, compromising the scalability and robustness of the dispatch.

Hybrid models, which combine different Artificial Intelligence techniques, emerge as a promising alternative to overcome the individual limitations of each approach. By integrating machine learning methods for forecasting, reinforcement learning for decision-making, and fuzzy logic for control and interpretation, these models seek to offer more robust and flexible solutions. The literature suggests that hybrid architectures exhibit superior overall performance, although challenges remain regarding design complexity, experimental validation, and implementation in real operational environments.

In general, the comparative analysis shows that there is no universally superior approach for intelligent load dispatch in photovoltaic systems. The choice of the most appropriate technique depends heavily on the characteristics of the system, the operational objectives, and the practical constraints involved. This finding reinforces the need for integrating structures that guide the selection and combination of Artificial Intelligence approaches—an aspect that supports the conceptual framework proposal presented in the subsequent sections, in line with trends identified in recent literature on hybrid energy dispatch architectures (HUANG *et al.,* 2025). The comparison between the main Artificial Intelligence approaches applied to load dispatch in photovoltaic systems is synthesized in Table 4.

Critical Discussion of Results

The integrated analysis of the selected studies shows that the application of Artificial Intelligence techniques to intelligent load dispatch in photovoltaic systems is a rapidly expanding research field, driven by the increasing complexity of modern energy systems. Recent literature converges in recognizing that the intermittency of photovoltaic generation, combined with the presence of storage systems and the need for multiple operational objectives, imposes challenges that are hardly met by traditional dispatch strategies based on fixed rules or deterministic optimization.

The analyzed results indicate that approaches based exclusively on machine learning, while effective in forecasting generation and demand, have limitations when considered a complete solution for energy dispatch. In many studies, the separation between forecasting and decision-making reduces the system's adaptive capacity in the face of unforeseen variations or abrupt changes in operational conditions. This finding suggests that, despite the high predictive accuracy achieved by these methods, their contribution to intelligent dispatch remains largely indirect—a result similar to that reported in recent reviews on predictive AI applications in photovoltaic systems (MATEO ROMERO *et al.,* 2022).

Conversely, reinforcement learning stands out as an approach more aligned with the dynamic nature of the load dispatch problem. The analyzed literature points out that formulating dispatch as a sequential decision process allows for a more natural incorporation of operational constraints, uncertainties, and conflicting objectives. However, it is observed that most studies still focus on simulated environments, with simplifying assumptions regarding power grid behavior, storage system degradation, and real-time information availability. This gap limits the generalization of results and highlights the need for investigations closer to real-world operating scenarios.

Fuzzy logic-based approaches remain relevant primarily in applications that prioritize interpretability and implementation simplicity. The critical analysis of the studies reveals that such methods are particularly suitable for smaller systems, where expert knowledge can be efficiently formalized into linguistic rules. However, as system complexity increases, the scalability of these approaches becomes a limiting factor, requiring additional adjustment and validation efforts that are not always feasible in practical applications.

A recurring point identified in the literature is the growing trend toward adopting hybrid models, which combine different Artificial Intelligence techniques to exploit their complementary advantages. These models reflect a more mature understanding of the load dispatch problem, recognizing that no single technique is capable of fully meeting the multiple operational requirements of modern photovoltaic systems. Despite the potential of these architectures, the critical discussion highlights that their practical implementation still faces challenges related to design complexity, computational cost, and the need for validation in real-world environments.

Overall, the critical discussion of the results reveals that, although advances in the use of Artificial Intelligence for intelligent load dispatch are significant, important gaps remain that limit their large-scale application. Among these gaps, the absence of standardized performance evaluation metrics, the still incipient consideration of long-term effects on storage system degradation, and the limited integration with regulatory and operational aspects of the power grid stand out. These aspects reinforce the need for integrating and conceptual approaches to guide the development of more robust, sustainable, and applicable solutions in real-world contexts, motivating the conceptual framework proposal presented in the following section.

Conceptual Framework Proposal for Intelligent Dispatch

Based on the critical synthesis of the analyzed studies, a conceptual framework for intelligent load dispatch in photovoltaic systems is proposed. This framework integrates photovoltaic generation, storage systems, the power grid, and Artificial Intelligence techniques into a unified decision-making architecture. The framework seeks to consolidate the main contributions from recent literature while simultaneously addressing the identified gaps, especially regarding the integration of forecasting, decision-making, and control in dynamic environments.

In the proposed framework, photovoltaic generation constitutes the primary energy source of the system, characterized by high temporal variability. Information related to instantaneous power, short-term forecasts, and environmental conditions is continuously monitored and made available to the dispatch module. These data represent the informational basis necessary for intelligent decision-making, reducing the uncertainty associated with system operation.

The Battery Energy Storage System (BESS) acts as an operational flexibility element, allowing for the temporal decoupling between generation and consumption. Within the context of the framework, the state of charge, power limits, and constraints related to battery degradation are explicitly considered in the decision-making process. This approach reflects a trend observed in recent literature, which recognizes the need to incorporate the preservation of storage lifespan as an objective of intelligent dispatch.

Electric loads represent the demand component of the system, which may include residential, commercial, or industrial profiles. The framework considers both instantaneous consumption and short-term forecasts, enabling decisions more closely aligned with actual user needs and the maximization of photovoltaic self-consumption. This integration allows load dispatch to shift from being purely reactive to incorporating predictive aspects. The proposed conceptual framework for intelligent load dispatch in photovoltaic systems is presented in Figure 8.

Figure 8. Conceptual framework for intelligent load dispatch in photovoltaic systemst learning for sequential decision-making, and fuzzy logic for interpretable control. The proposed architecture is flexible, allowing for the adoption of isolated or hybrid approaches according to system characteristics and operational objectives.

Overall, the proposed conceptual framework does not intend to replace specific models presented in the literature, but rather to offer an integrating structure that organizes and relates the main variables and decisions involved in the intelligent load dispatch of photovoltaic systems. By consolidating the findings of the systematic review, the framework contributes to guiding the future development of more robust, adaptive solutions aligned with the real demands of sustainable energy systems, in line with recent guidelines proposed in the literature on intelligent energy management (PERERA and KAMALARUBAN, 2021).

FINAL SUMMARY FRAMEWORK

In order to synthesize the main findings of this systematic review, the Final Summary Framework is presented. This framework consolidates the Artificial Intelligence approaches applied to intelligent load dispatch in photovoltaic systems, their predominant objectives, main advantages, recurring limitations, and the maturity level identified in recent literature. This table allows for an integrated visualization of the results discussed throughout the article, facilitating comparative understanding and reinforcing the core contributions of the research. The synthesis of the main findings of the systematic review, considering the Artificial Intelligence approaches, their objectives, and limitations, is presented in Chart 1.

CONCLUSIONS

This article presented a systematic literature review on the application of Artificial Intelligence techniques to intelligent load dispatch in photovoltaic systems, focusing on identifying the main approaches employed, their operational objectives, advantages, limitations, and technological maturity level. The analysis of studies published between 2020 and 2025 showed that load dispatch in photovoltaic environments has ceased to be a purely deterministic problem, now requiring solutions capable of handling variability, uncertainties, and multiple objectives in an integrated manner.

The results indicated that machine learning-based approaches are widely used, especially for generation and demand forecasting tasks, contributing to the reduction

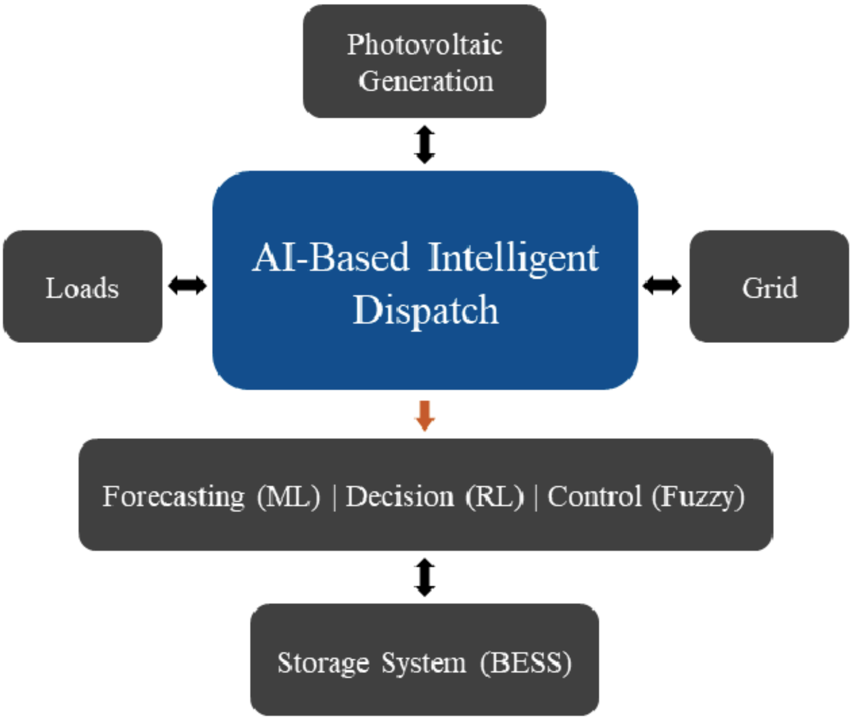

Figure 8. Conceptual framework for intelligent load dispatch in photovoltaic systems

Source: Developed by the authors (2026).

AI Approach	Main Objective in Dispatch	Main Advantages	Recurring Limitations	Maturity Level
Machine Learning	Generation and demand forecasting	High predictive accuracy; good modeling of non-linearities	Indirect decision--making; dependency on historical data	High
Reinforcement Learning	Sequential decision-making	Dynamic adaptation; multi-objective optimization	Computational complexity; limited practical validation	Intermediate
Fuzzy Logic	Interpretable dispatch control	Ease of implementation; interpretability	Reduced scalability; manual adjustments	Intermediate
Hybrid Models	Forecasting–decision–control integration	Robustness; operational flexibility	Complex architecture; high implementation cost	Emerging

Chart 1. Synthesis of AI approaches applied to intelligent load dispatch in photovoltaic systems

Source: Developed by the authors (2026).

of uncertainties in the decision-making process. However, it was found that these techniques, when used in isolation, have limitations regarding the dynamic adaptation of dispatch, since decision-making often remains based on rules or deterministic methods. In contrast, reinforcement learning proved particularly suitable for sequential dispatch problems, allowing for the direct optimization of operational objectives in dynamic environments, although it still faces challenges related to computational complexity and validation in real-world scenarios.

Fuzzy logic-based approaches remain relevant, especially in smaller systems that prioritize interpretability and implementation simplicity. However, their limited scalability restricts application in more complex architectures. In this context, recent literature points toward a growing trend of hybrid models, which combine different Artificial Intelligence techniques to exploit their complementary advantages. Despite the potential of these architectures, it was observed that their maturity level is still emerging, with a predominance of evaluations in simulated environments.

As the main contribution of this work, a conceptual framework for intelligent load dispatch in photovoltaic systems was proposed, integrating photovoltaic generation, storage systems, electric loads, the power grid, and a central AI-based decision module. The framework consolidates the findings of the systematic review and offers an organizing structure that can guide both future research and the development of applied solutions, without the intention of replacing existing specific models.

From a scientific perspective, this study contributes by systematizing the state-of-the-art, identifying recurring gaps in the literature, and highlighting the need for more integrative approaches applicable to the real-world operation of energy systems. Relevant gaps include the absence of standardized evaluation metrics, the still limited consideration of storage system degradation in the decision-making process, and the incipient integration of regulatory and economic aspects into intelligent dispatch strategies.

As perspectives for future work, it is recommended to investigate hybrid frameworks validated in real environments, the explicit incorporation of sustainability and longevity criteria for storage systems, and the development of scalable architectures capable of serving different consumer profiles and grid conditions. Thus, it is expected that advances in the application of Artificial Intelligence to intelligent load dispatch will contribute effectively to the efficient, sustainable, and resilient operation of photovoltaic systems within the context of the energy transition.

REFERENCES

ALANKRITA *et al.* **Fuzzy logic based energy management for grid connected hybrid PV system.** Energy Reports, 2022.

CHATZIGEORGIOU, N. G. *et al.* **A review on battery energy storage systems: Applications, developments, and research trends of hybrid installations in the end-user sector.** Journal of Energy Storage, vol. 86, p. 111192, 2024. DOI: https://doi.org/10.1016/j.est.2024.111192

HOSSAIN, M. S. *et al.* **Renewable energy integration challenges and solutions.** Energy Reports, 2022.

HUANG, B. *et al.* **Artificial-intelligence-based energy management strategies for hybrid electric vehicles: a comprehensive re-**

view. Energies, 2025.

IRENA. **Renewable Capacity Statistics 2023.** International Renewable Energy Agency, 2023.

KANG, H. *et al.* **Reinforcement learning-based optimal scheduling model of battery energy storage system.** Renewable and Sustainable Energy Reviews, 2024.

KUMAR, A. *et al.* **Artificial Intelligence Techniques for the Photovoltaic System: A Systematic Review and Analysis.** Archives of Computational Methods in Engineering, 2024.

LIU, H. *et al.* **Multi-objective hierarchical energy management strategy for fuel cell/battery hybrid power ships.** Applied Energy, 2025.

LUND, H. *et al.* **Review of energy system flexibility measures to enable high levels of variable renewable electricity.** Renewable and Sustainable Energy Reviews, 2021.

MATEO ROMERO, H. F. *et al.* **Applications of Artificial Intelligence to Photovoltaic Systems: A Review.** Applied Sciences, 2022.

MORALES, J. M. *et al.* **Integrating Renewables in Electricity Markets.** Springer, 2020.

PERERA, A. T. D.; KAMALARUBAN, P. **Applications of reinforcement learning in energy systems.** Renewable and Sustainable Energy Reviews, 2021.

REN21. **Renewables 2023 Global Status Report.** REN21 Secretariat, 2023.

SCHMIDT, O. *et al.* **The future cost of electrical energy storage based on experience rates.** Nature Energy, 2021.

WU, Y. *et al.* **Optimal battery capacity of grid-connected PV-battery systems considering battery degradation.** Renewable Energy, 2022.

XU, Y. *et al.* **Operational optimization for the grid-connected residential photovoltaic-battery system using model-based reinforcement learning.** Journal of Building Engineering, 2023.

ZAKERI, B.; SYRI, S. **Electrical energy storage systems: A comparative life cycle cost analysis.** Renewable and Sustainable Energy Reviews, 2020.