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A Systematic Review on Dispatch Strategies in Microgrids with Electric Vehicle Integration: Economic, Environmental, and Power Quality Perspectives

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Abstract

This study presents a systematic literature review of optimization approaches applied to energy management problems in EV-integrated microgrids. The optimization techniques are classified into three categories: classical, heuristic, and hybrid approaches. The analysis evaluates the effectiveness of each category based on their ability to improve power quality, enable cost-effective energy dispatch, and reduce carbon emissions. Results show that heuristic optimization techniques dominate this research area, accounting for 51.6%, with particle swarm optimization and genetic algorithms being the most commonly employed due to their practical versatility and adaptability. Classical techniques represent 22.5% of the approaches reviewed but exhibit limitations in solving highly complex and large-scale optimization problems due to restricted scalability and solving nonlinear system complexities. Hybrid optimization techniques account for 25.8% and demonstrate superior performance by leveraging the combined strengths of heuristic and classical methods. Hybrid approaches exhibit better convergence rates, higher solution accuracy, and improved scalability compared to standalone classical methods, making them particularly effective for complex, multi-objective optimization problems in EV-integrated microgrids.

Keywords: Energy management, Optimization, Electric vehicle, Microgrid, Economic dispatch

1. Introduction

The global primary energy supply is through the combustion of fossil fuels which are diminishing and often result in environmental degradation through greenhouse gas emissions. The increase in global population and advancement in technological innovation have yielded a spike in energy demand. Therefore, traditional non-renewable sources such as oil, natural gas, and coal are often utilized at a high frequency to meet the energy demand. However, this has led to environmental degradation that resulted in global warming and climate change [1–3]. The negative impacts of these non-renewable energy sources have exponentially driven the employment of distributed energy sources (DER) to form microgrids. A typical microgrid is a power network but on a smaller scale in terms of generating capacity. It can operate autonomously or in grid-connected mode[4]. Additionally, the development of microgrids as a new paradigm for electrical systems has expedited the use of renewable energy sources such as solar, wind, hydro, geothermal, biomass, wave, etc. which are less complicated when harnessed [5- 6]. All these renewable energy sources are driven by the goal of providing a reliable, sustainable, and stable power supply [7].

In the quest to mitigate environmental degradation, a broader view is being explored, not only in the power sector but in the transportation sector as well [9]. In 2022, the transportation sector contributed to 14% of the global greenhouse emission with road transport, aviation, and shipping being the major contributors. On the other hand, road transport also contributed 5.87 gigatonnes of CO2 by the end of 2022 [10]. The motor industry through research and innovation has subsequently entered the power sector through the EV as part of providing energy security, stability, and reducing the carbon footprint. The introduction of EVs into the power dynamic system in low voltage distribution networks is to provide ancillary services such as voltage support, load frequency control, and power correction [11, 12]. The development of smart grids has made the adoption of EVs very feasible [13]. EVs can be employed either as a load or source of power and when utilised with RES reduces uncertainties of power quality and mismatch of generation and demand [14].

There are numerous opportunities to enhance energy efficiency, improve grid reliability, and promote overall sustainability. There are several applications of EVs such as vehicle-to-grid (V2G), vehicles used in buildings, vehicles to infrastructure, vehicle-to-vehicle, and vehicle-to-other (V2X). V2G is the ability of a grid to supply and absorb power during different stages of operation of a grid/microgrid. A V2G needs an infrastructure where a charging station must be capable of handling two-way power flow [15].

The exponential growth of the EV sector affects electrical infrastructure as more charging stations are required resulting in high electrical energy demand which yields grid outages in peak hours, frequency fluctuation, and voltage imbalance [16]. This complexity necessitates the need to oversee and supervise the microgrid to achieve optimal control and functioning [17]. Therefore, microgrids can mitigate this risk by employing adequate and dynamic energy management approaches. An energy management strategy (EMS) is required to address the optimization challenges these new type of energy sources poses [18].

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Its thorough examination of electric vehicle integration into microgrids as a dynamic and adaptable part of energy management systems is what makes this research novel [19]. This study examines how intelligent control and bidirectional power flow can actively improve grid stability, energy efficiency, and overall system performance—as opposed to traditional research that views EVs only as mobile loads or passive participants. Additionally, to address the operational limitations of EVs and the stochastic nature of renewable energy sources, the article suggests an optimized EMS architecture. This offers a new method for creating durable, low-carbon microgrid systems [20].

There has been a lot of scientific work focusing on EV integration into the microgrid and the grid. In [21], the EV charging schedule was investigated based on unidirectional against bidirectional charging and centralised against decentralised using several optimization algorithms. The findings demonstrate that while centralized approaches offer superior scheduling plans with precise information on network loads, local charging permits greater penetration of EVs with less communication infrastructure. In [22] optimization approaches, converters, and controllers of EV converter configuration are investigated to explore the challenges and possible solutions of EV converter configuration. The aim is to find ways to improve the high switching and power loss that the converter exhibits. The review further investigates several pulse width modulation approaches to achieve the desired voltage and current. Artificial neural networks provided better peak efficiency, reduced ripple voltage, and total harmonic distortions. The review focused on highly referenced work in five pivotal optimization areas in EVs in the past twenty years. The areas are design optimization, optimal control, energy management, optimized charging and discharging, and routing with single and multi-objective methods to improve the driving range of Ev's and reduce the cost. Meta-heuristic optimization techniques and conventional and nature-inspired optimization algorithms were analysed, and results indicate that meta-heuristic can handle complex optimization challenges. However, there are limitations in the accuracy of the mathematical modelling, the need for a bigger database, and the importance of considering multiple constraints [23]. The machine learning technique was utilised for energy management in renewable microgrids with the integration of hybrid EVs. The objective is to have a reconfigurable structure based on remote tie-switching and sectionalizing. This study employed sophisticated and advanced stochastic optimization techniques, including the Gaussian Process Model and Krill Herd Algorithm, to optimize system efficiency and mitigate risks associated with renewable energy fluctuations. The technique utilizes the Gaussian Process (GP) to simulate the charging requirements of hybrid electric vehicles [24].

2. Contribution of the study

Optimizing microgrid performance in areas such as energy management, forecasting, and control requires more sophisticated techniques more so with the introduction of EVs in the power distribution network. The optimization techniques need to be robust to handle multi-objective cost functions instead of having static models, susceptibility to local minima, and prolonged computational times for complex problems. This limits microgrid operation and management, failing to account for the dynamic nature of microgrids. Many works in literature have looked at addressing optimization approaches in EV-integrated microgrids which mostly are focused on one objective function that deals with either power quality issues or economic dispatch (minimization of operational cost and reduction in pollution) in isolation. However, to the best of my knowledge, none have looked at these techniques holistically from a systematic literature review standpoint.

The major contributions of the paper are as follows:

The paper analyses the different optimization techniques employed to mitigate EV integration in electrical networks based on. Three spheres are economic dispatch (minimization of energy consumption), power quality, and environmental dispatch(minimization of pollutants). The aim is to have insight into energy management optimization techniques that specifically address the spectrum of economic dispatch, power quality, and the quest to reduce emissions to the environment through the integration of EVs into the microgrid.

The paper presents a state-of-the-art systematic review that analysis dispatch strategies in EV-integrated microgrids. Analysis is based on optimization techniques which are categorized into three classes which are classical approach, heuristic approach, and hybrid approach. An analysis was done on which is mostly employed to mitigate EV challenges to the utility network and provide possible solutions. This provides direction for future research and exploring advanced approaches such as machine learning to eliminate computational power to run complex models which take a lot of time.

The study provides insight into optimization approaches used to mitigate power quality issues, minimization of operational costs, and reduce the carbon footprint. Three optimization approaches are classified as classical, heuristic, and hybrid optimization to evaluate which optimization approach is frequently used to address EV economic dispatch, power quality, and environmental sustainability (minimized green gas emissions) challenges in EV-integrated microgrids. The motivation of the paper is to provide researchers on the developments in this field regarding optimization based on providing a more sustainable and resilient future energy that is not degrading the environment through greenhouse gas emissions and assist in providing recommendations to improve the EVs integration into the grid with robust optimization approaches.

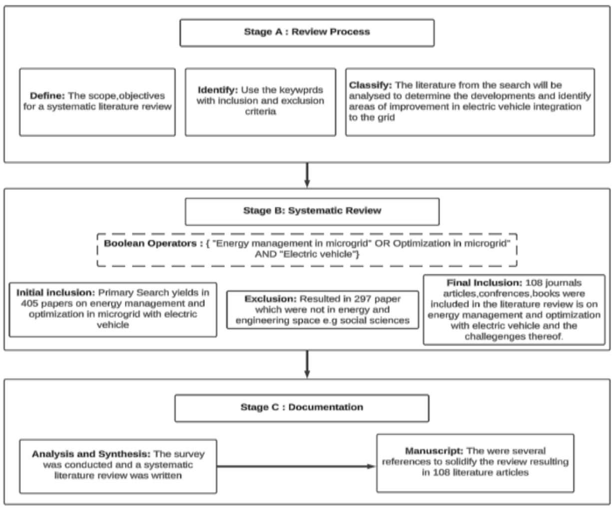

Fig. 1. Methodology flowchart.

3. Methodology

Formulating research questions that encompass the foundation and emphasis of the study is the first step in the research process. These inquiries stem from an examination of the various concerns raised by various works concerning the integration of EVs into the microgrid. There are three research questions this study seeks to answer which are:

RQ1: Are EVs worth being integrated into the microgrid, coupled with its power quality challenges?

RQ2: Which optimization approach is mostly used in EV integration with a microgrid as regards dispatch methods, and power quality and is better suitable for EVs in the microgrid to enhance grid resilience?

RQ3: Can several Optimization approaches be merged to provide optimal solutions in EV integrated into a microgrid?

For this review, Kitchenham systematic literature review methodology [25] and Kitchenham et al [26] methods are used. These are widely used approaches and have over the years been proven to provide a suitable and adequate methodology to systematic reviews. The elaboration of the three-stage used in the methodology is as follows:

Stage A will be to define the problem and identify the database for the review scope. The main aim is to populate the research articles and analyse them to identify research gaps in the literature. This helps to map the way forward in energy management and optimization of microgrids with EVs.

Stage B utilized three filtering steps to complete the systematic literature review. The initial literature study conducted research using keywords to gather several research papers relating to the introduction of EVs in microgrids, energy management, and optimization. The search included recent books, conference papers, review papers, and research articles. The review focuses on optimization techniques such as classical, heuristic, and hybrid optimization that deal with emissions reduction, power quality, and economic dispatch that incorporates the EV. The study does not include electric vehicle parts or converters, even motors are not included in this study.

Stage C Analyses the reviewed work and concludes, including future work that can be carried out to address outstanding gaps. The methodology's three stages are depicted in Fig. 1 above and explain actions taken in each stage to form this review.

The investigation utilised keywords that were specific to electric vehicle integration to microgrids, energy management, and optimization in highly regarded journals and conferences as depicted in Fig. 4 below. The search yielded 405 papers within 10 years (2014-2024) which can be seen in Fig. 2 below. A gradual increase in interest in EVs integrated into the microgrid can be seen in the spike in the number of publications over the years. Fig. 3 depicts the breakdown based on the overall share of publications analysed considering the conferences, journals, and reviews over the same period of 10 years. The search is limited to energy, engineering, computer science, and related fields while fields such as social science, material sciences, computer science, chemical engineering, etc. were excluded from the search criteria which resulted in a cut down to 108 papers. In 2012 only one paper [27] was published in this field. The number of publications steadily increased from 2014 to 2024 which shows a positive trajectory.

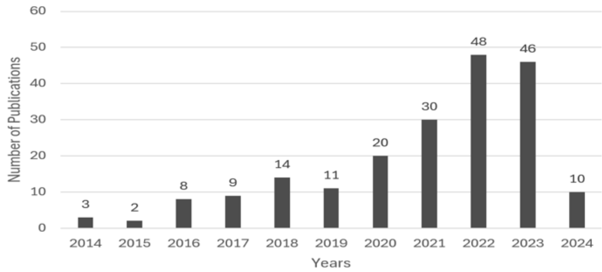

Fig. 2. Number of publications per year since 2014.

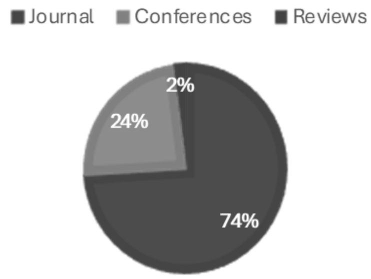

Fig. 3. Forms of publications in percentages.

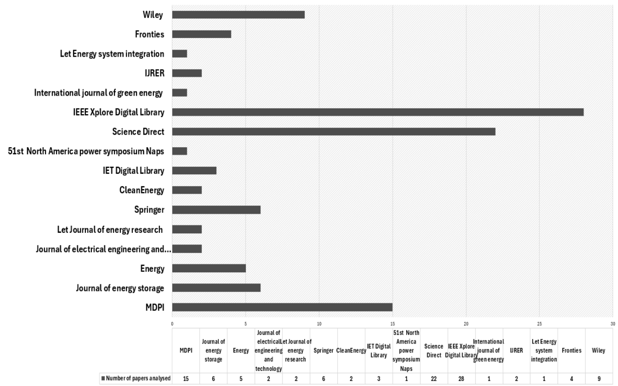

Fig. 4. Article reviewed sources.

4. EV integration in Microgrid

The state of modern energy systems is crucial, especially in light of the harm internal combustion engine cars bring to the environment and their role in contributing to global climate change [28]. These no doubt have triggered a need to transition from solely internal combustion engines to alternative solutions. As a result, the utilization of electrical energy in powering automobiles has been expedited which resulted in the development of EVs as part of the mitigation to reduce the global carbon footprint [29, 30]. Renewable systems have gained popularity in power distribution networks and this has included the integration of EVs [19]. This is to mitigate environmental damage caused by environmental pollutants such as hydrocarbons, carbon monoxide, and nitrogen oxides through combustion. Furthermore, the scarcity of fossil fuel reserves such as coal, petrol, and diesel has contributed to the migration from fossil fuel-based energy sources [31]–[33]. Vehicles are categorized based on the power source they use. There are internal combustion vehicles and electrical vehicles and there is a hybrid vehicle that uses both electrical and fossil fuels such as petrol and diesel [34]. Fig. 5 depicts the classification of several vehicles which include hybrid electric vehicles (HEV), all-electric vehicles (AEV), and ICEV.

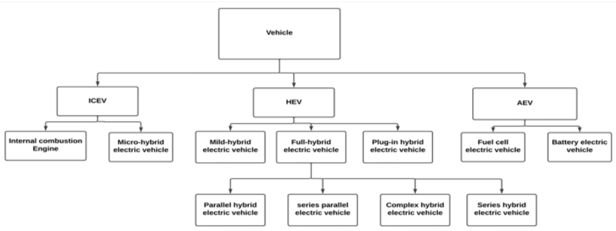

Fig. 5. Classification of EVs [34]

Vehicles are only driven 4% of their life, therefore the larger chunk of their time is in stationery and this could be utilized as an energy storage system [35]. The main remedy for the issues with internal combustion engines is the use of electric cars. The main justification for EV integration in smart grids is Vehicle-to-Grid (V2G) architecture which can be employed to leverage power networks and other businesses as a virtual power grid relative to the static power grid by using either unidirectional or bidirectional converters. The EVs can be utilized to absorb power generated from non-dispatchable power generators such as solar and wind generators and dispatch it during peak time [36]. Furthermore, EVs provide adaptability to the utility and aid in mitigating the imbalances [37]. This is made possible by advancements in electric vehicle technology and battery-charging technology [38]. EVs can also be utilized to supply critical loads during power outages in areas that are prone to natural disasters and areas without a stable grid. Additionally, they can assist in frequency regulation during the restoration phase [39]. However, the large penetration of EVs leads to high load demand due to the more energy used by a single charger. Furthermore, they give rise to a lot of uncertainty and nonlinearity because of high power input [40]. The overview of several energy management techniques that have been used to lower the risks involved with integrating electric cars into the power system is analysed. The use of decentralised coordination with accurate forecasting of traveling patterns can minimize load variability and provide stability to the grid integrated with EVs. The centralised coordination mitigates the voltage variation, and load variance power losses and reduces the computational complexities [41]. The reliability of an electric vehicle system is examined to comprehend the effects of power networks on the quality of the supply. It also explains the voltage levels needed for various electrical connections, including those used to charge batteries. The authors analyze the impacts of electric cars on power networks in terms of the quality of electricity generated by the grid, in addition to the effects they have on the reliability of the system. It explains the voltage levels needed for various electrical connections, including those used to charge batteries [42].

Table 1 below outlines the effects of EVs on the power network and the mitigation measures for those challenges. The stochastic optimization technique was devised to utilize idle vehicles to form a distributed energy storage to support the volatile power output from renewable energy sources[43]. Several architectures are employed utilizing electric vehicles relating to power systems. There are several benefits associated with EVs such as being able to produce no greenhouse gas emissions and reducing fuel costs [44].

Table 1. EV effects in power system

Reference	Impacts	Theory	Applicable Standards	Effects	Solutions
[45],[46], [47]	Harmonics	Power converters generate current harmonics due to non-linear behavior and non-linear electric switching. In EV harmonic current generated by the charger can damage the distribution transformer, cables, and protection devices.	IEEE 519-1992 Harmonic control in electrical power network. IEC 61000 Part 3 : Harmonic current emmissions	This distorts power quality.	High-frequency power converters can mitigate current harmonics and this results in soft switching capability. Improved filter designs
[48]	Stability	Ev requires a massive amount of power during charging in a short period resulting in power system instability.	IEEE 34 node feeder test 9 [Classical optimization]	This affects the power system and takes a great amount of time to get to a steady state.	Coordinated charging is proposed to reduce power loss using quadratic and dynamic programming.
[49][50]–[52]	Power Loss Increase	Simultaneous charging of EVs draws large power which results in power loss in the network. The major power loss occurs in power converters from AC -to DC. Power converter efficiency is low at low SOC and low power transfer. This further increases transformer losses and overloading.	IEEE 1547 Interconnection and interoperability of DER in Electric power network interfaces. IEC 61851 Testing methods for EV charging	The distribution network experiences power loss.	The optimal sizing of the charging station. The power dispatching algorithm is developed to firstly dispatch power among EVs equally and secondly dispatch power purposefully among EVs to reduce power loss.
[53],[54][52]	Phase Voltage Imbalance	Voltage instability leads to electrical power blackouts. The battery load requires more power to charge, and this affects grid voltage due to the load profile. This voltage drop or fluctuation will be experienced on distribution networks and interconnection points with EVs.	Interfaces. IEEE P2030 Interoperability of smart grids	Unpredictability during peak hours	The development of a charging schedule and even power flow would mitigate phase voltage imbalance.
[55]	Load Demand Increase And Components Overloading	Ev when being charged on the grid results in a 93% transformer lifespan due to overloading.	IEC 61000- Part 3 Part 3: Harmonic current emissions	This reduces equipment lifespan from transformers	It requires expensive-rated conductors.

				to protection equipment.	
[56]	Power Quality Improvements	Smart scheduling of EV charging/discharging through V2G can support the grid in reducing peak demand by dispatching power. EVs are used in peak shaving and valley filling of grid load profiles. This is attained through using PSO.	IEEE 33 Bus distribution system (PSO)	Poor power quality degrades system life.	A coordinated electric vehicle grid integration (EVGI) can mitigate voltage surges and injection of harmonics.
[14],[57]	Voltage And Frequency Regulation	The EV is deployed to compensate for the volatility of renewable energy sources therefore regulating the frequency perturbations.	IEEE1547 Interconnection and interoperability of DER in Electric power network	Voltage and frequency fluctuations affect power quality and system lifespan.	Injection of reactive power. Reducing network frequency deviation can assist with frequency regulation.
[58]	Renewable Energy Support	Renewables limit reliance on the power network, help in the reduction of carbon footprint, and provide flexibility to the utility.	IEEE1547 Interconnection and interoperability of DER in Electric power network	The intermittency nature of renewables leads to uncertainties	Ev can be utilized to cushion renewables, therefore reducing cost and carbon footprint.

5. Microgrid energy management with electric vehicle

The employment of several DG requires a control system that will monitor and supervise for efficient operation, and coordinate different sub-systems to reach a predetermined goal. This system is known as an Energy Management System (EMS) which will ensure that adequate power sharing is implemented, reduction in greenhouse gasses, reduction in operational cost, and increase the machinery lifespan [59]. EMS is a computer-based software platform that provides assistance services and a set of applications that gives the functionality required for the effective operation of electrical generation and transmission systems to have robust and adequate security to provide continuous power supply at a minimized cost as per International Electro-Technical Commission (IEC) 61970 standard [60]. EMS in microgrid is the ability to provide continuous power flow by control and optimization of distributed generators in the microgrid. This entails monitoring, controlling, and analysing power generation, storage, and power usage for efficient and reliable operation. Microgrid can operate in two modes which are islanded mode and grid ties mode as depicted in [61] below. Therefore, EMS has different tasks depending on the operating mode. In an islanded mode of the microgrid, the primary objective is to prevent the mismatch between supply and demand. In grid-tied mode the tertiary control deals with synchronization and in case of a grid failure or disturbance regulates power flow between the utility and microgrid to maintain appropriate power quality at the point of common coupling (PCC) [15], [61].

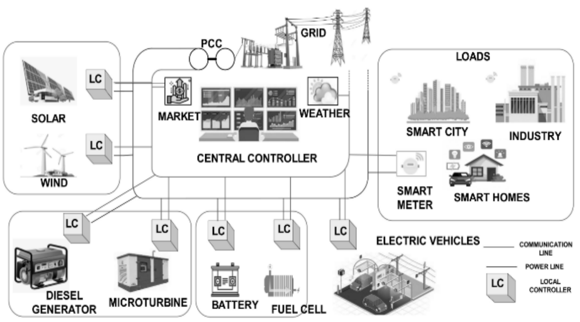

Fig. 6. Grid tied Microgrid structure

Furthermore, EMS is responsible for power exchange between distributed energy sources, energy storage systems, loads, and external networks determined by the control employed. This ranges from heuristic principles to complex optimization algorithms. As a result, EMS maximizes the use of renewable energy sources and energy acquired outside the microgrid. It seeks to reduce operational expenses, energy losses, fuel usage, and GHG emissions. Moreover, it deals with resynchronization with the main network and improves systems reliability by maximizing consumer energy availability [62, 63].

The expeditious growth of EVs will account for between 11%-28% of the world's transportation by 2040. Consequently, resulted in an 11%-20% in global electrical energy demand. Thus the rapid development of RES will pose a huge challenge to the power network [64, 65]. This will consequently lead to power grid complexity as that could give rise to peak power demand and affect transmission and distribution capacity which is however mitigated by the intelligence embedded in the microgrid. The major challenge for EV as the load is the peak-to-valley difference in the load profile during charging. This disrupts the network operation and can result in poor electricity quality and damage to the infrastructure. The EV charging load is influenced by several factors such as the battery characteristics, the number of users, charging behavior, and the method of charging. Therefore those form several disturbances [18]. The randomness and fluctuation of charging especially in large numbers where EVs are integrated is unavoidable. Therefore, one mitigation measure is the use of Monte-Carlo as a prediction tool which utilizes probability statistical theory and approach. The technique ties a problem to a probability model and employs a computer simulation to provide an approximate solution [66].

The work to fully provide an effective energy management approach that addresses adequately the uncertainties of RES in microgrids and multiple microgrids has focused mainly on power output from RES such as wind turbines and solar PV due to their dependence on weather conditions [67]. The approaches mostly used are scenario-based stochastic energy management and uncertainty-based robust energy management methods. These methods employ several number scenarios and minimization of the objective function however, this large number of scenarios requires massive computational ability when incorporated in optimization models [68–70].

6. Optimization Approaches in EV-integrated Microgrid

The microgrid is a cluster of several electrical sources, energy storage units, and controllable and uncontrollable loads including EV which can be either a load or energy source [71]. EVs are employed to deal with the overflow of power from the utility by charging the battery pack and mitigating outages and continuous power during peak hours [72]. This new paradigm of microgrids in electrical energy systems that incorporate distributed generators is prone to volatility and randomness. Therefore, the traditional energy management system is inadequate to satisfy the prescribed requirement to ensure the security and stability of the grid [73]. Proper functionality of EMS requires intelligent algorithms, running models, and the employment of optimization strategies to operate the microgrid most cost-effectively [74]. The primary goal of microgrids' extensive automated energy management is to achieve optimal resource scheduling, and efficiently manage energy flow and charging/discharging schedules of EVs. It can maximize the administration of DER and energy storage systems due to the built cutting-edge information technology [75–77]. The optimization needs also to consider constraints such as power balance, safety limitations, EV charging rates, fuel supply limitations, and pollutant emissions [78]. The optimization space has witnessed an evolution due to significant changes in the electrical sector in integrating several DERs including EVs into the grid. Therefore, there are various optimization approaches to obtain the best possible solutions to a challenge by either maximizing or minimizing the objective function as depicted in Fig. 7. However, there are limitations in optimization techniques due to varying variables and uncertain parameters.

The study of the optimization of systems in engineering space is from ancient times and power systems are no different. It has been enhanced over time by the developments in computational and mathematical programming methods, but it predates the invention of digital computers which completely transformed numerical optimization and computation [79]. Electrical systems optimization is a tricky process due to its erratic nature of power generation and the fluctuating demand for energy which is especially true given the widespread employment of RES such as wind and solar PV. Most of the configuration methods now in use have primarily concentrated on the issue of finding the best solutions for energy management issues in the smart grid. The adaptability and the stochasticity of smart grid functions are too much for the present generation of classical optimization methods. Consequently, the computational methods and tools necessary are described as a platform for evaluating, coordinating, operating, and planning the smart grid in various uncertain situations [80].

There are several methods utilized in solving optimization challenges in a division of classical optimization techniques such as dynamic programming, mixed integer programming, and linear and non-linear programming. Dynamic programming is utilized in discretizing and sequencing more complicated problems. Linear programming uses real-valued and whole-valued decision variables as linear functions to formulate objective functions and constraints. Metaheuristic and heuristic optimization use approximate adequate solutions and they are genetic algorithms, biological evolution, and statistical mechanisms. Prediction control approaches are applied where forecasting generation and loading are required to ensure efficient management of stored energy. Usually, it mixes stochastic programming and control. Multi-agent optimization approaches for microgrids provide decentralized administration through autonomous portions executing set tasks. These agents, which comprise loads, distributed generators, and storage systems, communicate with one another to achieve the lowest cost. In fields like artificial neural networks, fuzzy logic, and game theory, stochastic techniques, and resilient programming are employed to tackle optimization problems with random parameters. A few more approaches may be generated from a mixture of the aforementioned strategies, including stochastic and heuristic approaches, as well as the enumeration algorithm.

Optimizing EV in microgrids encooporates several strategies to improve effiviency and reliability. Intergration of green energy sources for charging EV enhances the sustainability while machine learning approachs promotes smart charging. Therefore that smart charging optimizes schedules in real-time [24]. Table 2 below outlines the recent work on different types of optimisation classified as classical, heuristic and hybrid optimization. It focusses on the contribution and categorises the contributin based on either power factor, economic dispatch strategy or environmental dispatch strategy.

Table 2. Optimization approaches in recent literature

Reference	Type of Optimization	Contribution	Economic/Environmental/power quality
[18]	Non-dominated sorting Genetic Algorithm (NSGA-II)	The continuous power supply and the sizing are made through the Monte-Carlo method to do the charging selection, waiting time, and battery size selection for the campus microgrid. The system is modeled, and the NSGA-II algorithm is utilized for optimization. Moreover, EV to participate in injecting power into the network to earn income through power sales when there is a huge gap between peak and off-peak electricity prices.	Environmental, economic, and power quality
[14].	Adaptive model predictive control (AMPC)	The author seeks to address energy management and control issues of microgrids. The distributed generators comprise renewable sources such as solar photovoltaic, energy storage, wind turbines, ultracapacitor loads, and six electric vehicles. The objective is the charging and discharging optimization and minimizing the operation cost of renewables using AMPC. The algorithm determines the sale of electrical energy to the grid and manages the distributed energy resources. The notion of EV to have the ability to dispatch power to the grid was investigated. The EV and microgrid energy storage systems were used to maximize savings and compensate for the volatility of renewable energy sources therefore regulating the frequency perturbations. When load shifting was implemented to address the charge control issue during interval parking the cost was reduced when EVs were connected to the microgrid compared to when it was not.	Power quality & economic dispatch
[81]	Dynamic and adjustable Manta-Ray Foraging (DAMRF)	By utilizing Evs inherently flexible as controlled loads, the DAMRF algorithm creates a thought dispatch model for large-scale EV	Economic dispatch and environmental

		response. The microgrid load response is accounted for in the model along with the management, operation, and environmental cost.	
[82]	PSO	The microgrid comprises of wind turbine, photovoltaic, and battery storage system with the compressed air energy storage (CAES). The author tests two scenarios (1) planning microgrid and DR without considering CAES and (2) planning microgrid and DR with the consideration of CAES to evaluate the cost of charging and discharging the EV. The scheduling is done in the IEEE 32 bus network comparing the improved harmony search (IHS) algorithm and PSO which PSO proved superior.	Economic dispatch
[83]	Adaptive robust optimization (ARO)	The coordination of the EV aggregator and the distribution network operator to reduce the system cost by utilizing a decentralized robust model. A decentralized algorithm is built on the alternating direction method of multipliers to solve the robust optimization-based model.	Economic dispatch
[84]	Non-dominated sorting Genetic Algorithm (NSGA-II)	The multi-objective functions were utilized to optimize the model to extend the battery lifespan, minimize the generation cost, electric vehicle recharge price, and uncertainty cost function to cater to the volatility of renewable sources.EVs are considered for demand-side management is considered to mitigate power mismatch that is due to renewables. These NSGA-II are employed to attain the global best solution for operation parameters.	Power quality and Economic dispatch
[85]	Adaptive simulated Annealing particle swarm optimization(ASAPSO)	The study employed two objective functions which seek to minimize operation cost and environmental protection costs. Furthermore, the unscheduled charging and discharging of EVs is simulated using the Monte Carlo method. The two objective functions were converted to a single function by solving a linear weighing method by a two-person zero-sum game. The microgrid scheduling was optimized by ASAPSO	Economic dispatch and environmental
[86]	Whale optimization algorithm (WOA) and teaching and learning-based optimization (TLBO)	The primary goal of the microgrid is to reduce the fuel usage of the diesel generator (DG). The microgrid comprises PV, wind, pumped hydropower (PHS), and EVs. PV and wind energy are the primary suppliers of the load. The mismatch that is experienced is catered by PHS and DG. The modified charging/discharging is proposed to examine the EV impact to supply a portion of peak loads with pumped hydro storage to reduce the diesel generator fuel cost and the WOA and TLBO meta-heuristics are compared and WOA proved superior.	Economic dispatch and environmental
[87]	Fire hawk optimization (FHO) and hybridized whale particle swarm optimization (HWPSO)	The quest to improve power quality challenges due to EV charging that results in power losses, voltage deviation, and voltage unbalance factors. This is attained by minimizing the dependence on the utility to charge the EV. This is through the FHO and HWPSO to simultaneously reduce EV load charging to improve power quality. The uncertainties such as power output from PV and SOC are simulated using the Monte Carlo method. Distribution static synchronous compensator, PV, and EV charging stations are optimally located to enhance voltage stability in the distribution network.	Power quality
[88]	Hybrid grey wolf-whale optimization (HGW-WO)	The need to reduce emissions and maximize the economic benefits is proposed through the DG, RES, and PHEV. The proposed framework also includes the elasticity-based price which argues the demand response to energy management complexities to examine the impact of dynamic energy pricing and rewards to customers. The power trading between microgrids and the utility can minimize the operational cost of the microgrid through precise scheduling considering uncertainties such as EV charging, load demand, and fluctuating power output from RES. The bi-level HGW-WO) was employed to initially optimize the microgrid to attain dynamic price and load demand modification and then to minimize the microgrid's operational cost.	Economic dispatch
[89]	Genetic algorithm-particle swarm optimization (GA-PSO)	The primary goal is to minimize voltage fluctuation, power loss, EV battery cost, demand-supplying cost, and EV charging. RES and EV charging are regarded as optimization variables. The sizing of RES was adequately implemented and the location as well as EV charging stations assisted in improved power system voltage. This multi-objective optimization problem was solved using the GA-PSO technique.	Power quality & economic dispatch
[90]	Particle swarm optimization (PSO)	The aim is to reduce the effects on the grid so, to attain that is to mitigate the challenge posed by the residential loads and the concentrated power usage by the EVs. This is best achieved by addressing these challenges when the electricity costs are low. The multi-objective PSO is used to effectively schedule the loads and EVs whereby users' habits are taken into consideration as well as time-sharing tariffs.	Power quality & economic dispatch
[91]	Particle swarm optimization (PSO)	The primary goal is to reduce operational costs with thermal and electrical loads. Therefore, a two-level hierarchical multi-agent is utilized to achieve that at a microgrid level. The PSO is used to optimize energy used by the buildings and minimize operational costs to have financial benefits.	Economic dispatch

[92]	Multiobjective Particle swarm objective and Harmony search (hMOPSO-HS)	The primary aim is to minimize microgrid operational costs and improve the voltage stability index. The model caters to the uncertainties of DGs, RES, electric vehicle parking lots, and the load. The hMOPSO-HS is used to simulate and that is done in two phases; where no uncertainties are considered and when they are. Furthermore, a comparative analysis was performed between hMOPSO-HS and multiobjective differential evolution(MODE), NSGA-II, MOPSO, and multiobjective gray wolf optimization(MOGWO). The hMOPSO-HS proved to be superior in cost minimization and improving voltage stability.	Power quality & economic dispatch
[93]	Mixed integer linear programming (MILP)	The employment of EVs at the Los Angeles Airbase is piloted with California's independent system operator for involvement in the frequency regulation market. The hierarchical control is used to optimize, plan, and control the grid response, charging, and bidding. This utilizes a day ahead optimization utilizing MILP for charging, regulating capacity bids, and minimization of operation costs.	Economic dispatch
[94]	GA	The quick response time and V2G abilities were utilized to improve the frequency stability of the power system.GA and integral time absolute error are employed to attain adequate optimality of the controllers(PI and PID control)	Power Quality
[95]	Multi integer non-linear programming (MINLP) and Grey wolf optimization (GWO)	The optimal charging and discharging of EVs in aggregator with drivers charging behavioral patterns and reduce CO2 emissions from the utility, minimize the operating cost of a distribution company, minimize power loss The problem was formulated based on the MINLP model. A GWO was then employed to compensate for MINLP's inadequacy in solving problems using exact methods.	Economic dispatch and environmental and power quality
[96]	Model prediction control (MPC)	The use of two-stage economic optimization was implemented. The initial stage involves the solving of economic optimization challenges at the day ahead time scale to ascertain the amount of power acquired from load service entities and calculate the best pricing while catering for uncertainties associated with EVs.The second stage is to satisfy EV requirements and reduce operational costs using a real-time model predictive method.	Economic dispatch
[97]	Rolling optimization (RO) and Model prediction control (MPC)	The development of a two-layer model predictive control is proposed for EV charging from the microgrid due to the uncertainties in the EV aggregator. The unpredictability in SOC sampling findings of each EV at the microgrid and EV connection times sampling yields multi-uncertainties sampling is catered for using RO and MPC.	Economic dispatch and power quality
[98]	Multi integer linear programming (MILP) and Model prediction control (MPC)	EVs were taken into consideration as mobile energy storage devices for developing a standard MPC for a grid-connected home microgrid, to reduce total operating And remove the detrimental effects of the prediction mistakes for renewable energy. A MILP is employed to optimize at every decision-making moment based on the production of renewable energy resources, load demand, and price of electricity, as predicted in the short term. To lessen the detrimental effects of forecast mistakes, this MILP issue is included in an MPC architecture.	Economic dispatch
[99]	Hierarchical Model prediction control (HiMPC)	This research provides a hierarchical model predictive control (HiMPC) based energy management system for smart grids utilizing electric cars. Load-frequency control (LFC), economical operation, and integration of electric vehicles into the smart grid are made possible by the energy management system. The key component is the HiMPC, which uses a systematic model- and optimization-based design to reject disturbances (like those caused by fluctuating renewable generation) and cover various time scales concerning constraints (like power ratings) and predictions (like those on renewable generation). An aggregator is suggested as a connection point between HiMPC and the specific vehicle for the integration of electric vehicles. Specifically, the aggregator forecasts the HiMPC when electric cars will be available for LFC based on statistics on mobility and the present mobility demand.	Economic dispatch and power quality
[100]	Elephant herding optimization (EHO)	The primary goal is to reduce the microgrid operation cost moreover to optimize the cost of energy to the consumers using a dynamic pricing method. The fuzzy-based technique is utilized to minimize the operating cost considering cost and load variance index while maintaining the stability of the microgrid. The V2G and G2V topologies are integrated into the microgrid to aid in peak shaving and valley filling of the loads during peak and off-peak hours. The EHO is employed to tackle the presented complicated combinatorial optimization issue.	Economic dispatch and power quality
[101]	Dynamic stochastic optimization (DSO)	The study focuses on using a gridable EV as a virtual power plant and smart parking as a portable power plant. The utilization of the DSO technique enhances the benefits of RES by automatically scheduling and coordinating non-stationary sources. Therefore the attainment of load demand leveling, minimization of operational cost, and emission cost finally increase in reverse and reliability of the smart grid.	Environmental

[102]	Fuzzy Logic and Convolutional Neural Network (CNN)	Since timely frequency management is needed, autonomous MG operation with RES is even more difficult. The primary aim is to minimize power loss and voltage fluctuations. Three execution stages make up the EMS: EV storage allocation, optimal power allocation for fleet, and ranking for EV recommendation. In the third step, an intelligent Convolutional Neural Network (CNN) with an output rank of EV and four input decision variables is trained using the data obtained from the fuzzy rule basis. At this point, minimizing battery deterioration and maximizing its potential are the major objectives.	Power Quality
[103]	Machine learning	Battery lifespan can be achieved by devising a plan to cut down on the number of charge cycles while retaining the efficiency of power distribution from battery storage. The EVs globally are increasing at an exponential rate thus unique to the profitability of EV batteries will be investigated. The study employs machine learning to provide a cost-effective dependable and high-performance energy storage system.	Economic dispatch
[104]	Biogeography-based optimization	The community microgrid energy management when EVs residential charging stations are integrated with microgrid. The biogeography-based optimization is utilized to optimize the cost when provided with load profile, RES generated power, and current electricity prices.	Economic dispatch
[105]	Second-order cone programming (SOCP)	In recent years, a research priority has been how to balance the need for large-scale electric car charging and discharging with the safe functioning of the distribution grid. To address this issue, a first mathematical model was developed. Secondly, the improved SOCP method transforms the optimal solution following the nonlinear characteristics of the optimization model, allowing us to find the optimal solution quickly and accurately and solve the issue.	Power quality
[106]	Artificial hummingbird algorithm (AHBA)	AHBA is a proposed optimization approach to a smart home energy management system for optimal power dispatch PV, energy storage systems, and EVS to maximize economic benefits to the customer. This optimization considers unpredictable energy use from EVs, fluctuation in household load demand, and the intermittent nature of PV power output. The author caters to future EV power requirements based on initial and planned SOC as well as the arrival and departure time.	Economic dispatch
[107]	MILP	The quest to reduce emissions and provide effective cost is the primary goal of the study. The MILP is utilized considering electricity price, purchasing price, and simulation to mimic actual conditions in the microgrids and diverse demands from the consumers. The assessment of reactive power from the network is done following regulatory rules.	Economic dispatch and power quality
[108]	Linear Programming	The study aims to minimize microgrid operating costs and increase energy storage use while adhering to the constraints. LP and heuristic approaches were utilized to validate if V2G can be implemented. LP proved to be a superior approach for V2G implementation.	Economic dispatch
[109]	State flow algorithm	The power generation and energy management of a microgrid that comprises a diesel generator, solar PV, and electric vehicle is carried out to provide an uninterrupted energy supply. State flow algorithm was employed in MATLAB Simulink environment using state of charge of EV battery and the load power and generated PV power. Direct voltage control is employed to regulate the AC load voltage.	Power quality
[110]	GA	The techno-sustainable-economic framework is proposed for scheduling the multi-microgrid with RES, conventional generators, and energy storage systems. The aim is to reduce the power losses and minimize the operational cost. The GA is used to model multi-objective scheduling and the testing was performed on the IEEE 33-bus test system.	Economic dispatch and power quality
[111]	GA	The aim is to smoothen the fluctuations due to high EV penetration that is integrated into PV farms in the microgrid. The initial step is the development of energy management that considers the scheduling of EVs integrated into a microgrid with a charging station using MATLAB then proceeds to real-time digital simulation (RTDS).GA is used to minimize the cost of charging and discharging by scheduling EVs for 24 hours in a MATLAB environment.	Economic dispatch and power quality
[112]	Modifies sparrow search algorithm (MSS)	There are benefits to EVs and RES however there is a challenge to managing several PHEVs with RES. The aim is to solve the management of PHEV with RES to provide scheduling in the microgrids. The main objective is to reduce operational costs. MSS is used to solve this optimization challenge and modeling of PHEV and load was done using Monte Carlo simulation.	Economic dispatch

[113]	Crow search (CS)	CS is used to solve the challenge of multiple energy sources that deal with the transmission and production energy of electricity and natural gas in the microgrid with the integration of EVs. This is caused by the interplay of several energy sources, RES unpredictability, electricity prices, and varying energy demand from the consumer. The EV acts as both the source and load and it is utilized for effective demand-side management.	Economic dispatch
[114]	Hybrid crow search and pattern search (HCP-PS)	The day ahead operating challenge in the microgrid with RES and PHEV is examined. Monte Carlo is used for optimal management of the microgrid to adequately model uncertainties. The uncertainties considered are electricity price, output power from RES, and charging requirement for PHEV to have a 24-hour day-ahead model. The aim is to reduce the operating cost, so HCP-CS is utilized to address the problem's high level of complexity.	Economic dispatch
[115]	Improved bald eagle search algorithm(IBESA)	The objective is to minimize actual power loss, minimize system voltage fluctuation, limit operational expenses, decrease bus voltage volatility, and lessen CO2 emissions. The electric charging stations placement issue is optimized inside the multi-objective SCOPE framework by means of an improved bald eagle search algorithm(IBESA). The model takes into consideration user driving habits and vehicle-to-grid (V2G) capabilities during a 24-hour period. This study illustrates the effectiveness of integrating solar-based distributed generation and Distributed static VAR compensator in reducing the SCOPE index, thereby validating the benefits of the proposed IBESA algorithm. It offers a comprehensive solution to the complex challenges related to the integration of Electric Vehicle Charging Stations (EVCS), presenting a sustainable and optimized framework for future smart microgrids. The findings indicate that the combination of SDGs and DSVCs significantly contributes to lowering the SCOPE index, underscoring the advantages of the proposed methodology.	Economic dispatch and power quality
[116]	Complex Linear Proggramming Expert (CPLEX), PSO and genetic algorithms	This study examines the effects of EV charging management and energy storage system (ESS) configurations on photovoltaic (PV) consumption in a village microgrid context. It underscores the benefits of co-optimizing load management strategies alongside ESS configurations to optimize PV consumption.The unordered charging load curve of EV users was simulated. The MATLAB platform with YALIMP&CPLEX tools to solve the EVs orderly charging model, and the Monte Carlo approach to simulate the disorganized charging of EVs were utilised. To optimize the ESS setup, two methods are used: particle swarm optimization (PSO) and genetic algorithms (GA). The aim is to optimize orderly charging to reduce load peak-valley difference, to increase PV consumption optimize the configuration of energy storage.	Economic dispatch
[117]	Slap Swarm optimization Algorithm(SSA) and State Machine Control (SMC)	The objective of EMS are to reduce the battery current fluctuation caused by both the SynRM and PWM inverter; stabilize the DC-bus voltage; ensure the effective utilization of power transfers between the battery and SC; maintain the necessary power quality and system stability during abrupt transitions between different operating modes; and use a combination of diverse strategies to achieve optimal performance. The EMS integrates the advantages of the SSA and SMC to enhance system performance and prolong battery life. The rapid optimization capabilities of the SSA facilitate real-time adjustments to improve the SMC. This strategy focuses on optimal adaptive state machine control to effectively manage power from both battery and supercapacitor sources.	Power Quality
[118]	Nash-Cournot mdel and stochastic optimization model	The primary objective of this study is to simulate how fluctuations in the number of electric vehicles (EVs) affect the optimal stochastic operational decisions of the microgrid and the electricity market. This simulation is conducted within the context of the uncertainties associated with grid supply and demand, particularly in light of the ongoing liberalization of Taiwan's electricity market. The impact of microgrids and electric vehicles (EVs) on the competitive power market is investigated in this study using a stochastic optimization model and the Nash-Cournot model. While the stochastic optimization model models the operations of both EVs and microgrids in the face of uncertainty, the Nash-Cournot model concentrates on the interacting behaviors of microgrids in this market. By combining a linear complementarity problem (LCP) framework with a Nash-Cournot competitive model for the electrical market, the research develops a stochastic optimization model to evaluate the best performance and operation of microgrids across a range of uncertain situations. To further mimic the integration of EVs into microgrids, a Poisson process is used.	Economic dispatch

Table 3. Optimization Techniques Pros and Cons and Applicability [119]

Optimization Method	Pros	Cons	Applicability
Classical Optimization (MILP, QP)	Easy to implement Low use of memory	High computational time Intractable Non Flexible	Electrical Distribution Day ahead optimization
Hereustic (MPC,GSA,PSO)	Tractable Quick transient response Receives real-time feedback	Requires a system model High computational time	React to uncertainties Electric mobility Residential and commercial microgrids' real-time operation
Hybrid Optimization(Machine learning, AMPC, Fuzzy Optimization)	Adaptable Flexible Low- Medium computational time	Needs historic data Minimal computational time	Real-time Operation Electric mobility Residential and commercial microgrid's real-time operation

Table 4. Summary Comparison of Optimization Methods

Optimization Method	Convergence & Accuracy	Scalability
Classical	Low convergence and accuracy especially for non-linear systems	Limited
Hereustic	Provide near-optimal solutions	High
Hybrid	High convergence and accuracy rate	High

7. Results

There has been a significant improvement in the development of algorithms employed to solve uncertainties in the microgrid from the classical methods (traditional). The classical method is used depending on the type of loads and generators [120]. The challenge with the traditional optimization techniques is that they are limited to linear systems and they can not linearize the problem formulation in a short period. When multiparameter programming is used it cannot solve–integer and non-quadratic systems due to the possibility of critical region to increase [121]. Heuristic optimization approaches are widely employed because of their convenience in application for multidimensional problems. PSO is the frequently used approach is solves multi-objective problems by reducing computational complexities relative to the rule-based approaches and the classical optimization techniques and is highly scalable [122]. The hybrid optimization approach has a high convergence rate and accuracy rate relative to standard heuristic and the classical approach [123].

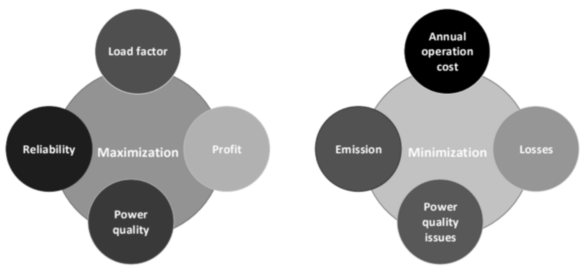

Fig. 7. Objective functions of EVs [124]

The study analyzed scientific articles published in the last ten years, as shown in Table 3 based on dispatch strategies. The optimization techniques are categorized into three types namely: classical optimization, heuristic optimization, and hybrid optimization. The objective is to figure out which are mostly employed optimization techniques for different dispatch strategies to address energy management optimization challenges. The dispatch strategies are also classified into three categories namely power quality, economic dispatch, and environmental dispatch strategy. This study distinguishes between economic dispatch, which focuses on minimizing energy consumption, and the related goal of reducing pollution levels in the environment which is then classified in the environmental dispatch strategy. To provide insights into recent advancements, the study examines the integration of electric vehicles (EVs) in utility networks and microgrids.

Figure 8 analyzes the optimization approaches from Table 2. It shows that the heuristic optimization method is the most commonly used, accounting for 51.6% of the techniques reviewed. Hybrid techniques make up 25.8%, while classical techniques account for 22.5%. Particle Swarm Optimization (PSO) and hybrid optimization that has PSO algorithms are particularly popular due to their simplicity and ability to arrive at good solutions very quickly. Furthermore, it is capable of handling non-linear and multimodal optimization problems. To their simplicity and effectiveness in solving complex optimization problems.

The review did not consider the cyber threats related to the EV integration into the microgrid as it is not the focus of this study.

Furthermore in this study, the evaluation of the economic dispatch category was explored and which optimization algorithm is most used to attain a global solution in that regard. Heuristic approaches cater for 53.3% of the total economic dispatch work then classical and hybrid approaches account for 26.67% and 20% respectively as seen in Fig. 9 above. The study further analysed which optimization techniques are frequently used in economic dispatch between classical, heuristic, and hybrid (Table 4). The heuristic optimization technique is mostly utilized and results are depicted in Fig. 8 below.

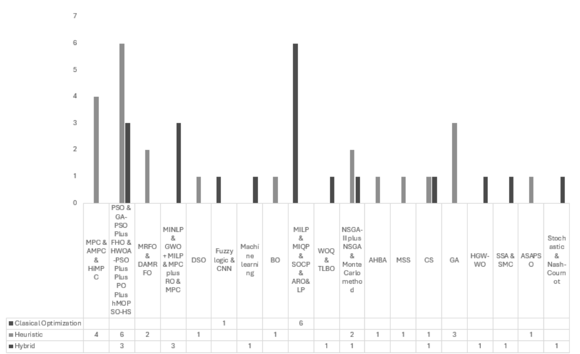

Fig. 8. Reviewed Optimization Method results

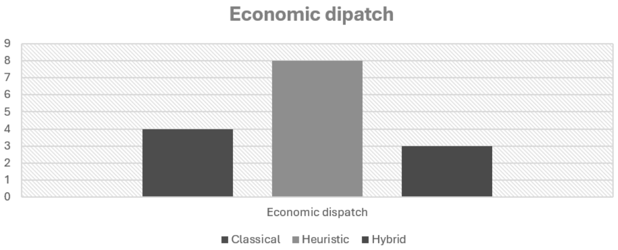

Fig. 9. Optimization Approaches for Economic Dispatch: A Comparison of Classical, Heuristic, and Hybrid Methods

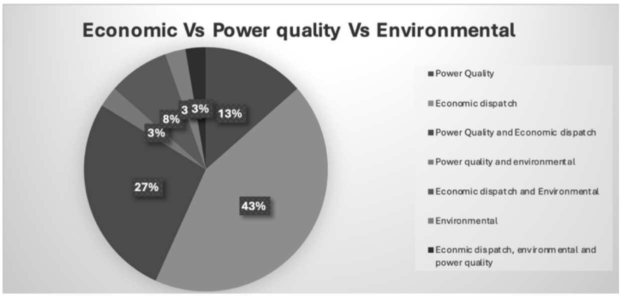

Fig. 10. A Research Focus on Optimization Techniques in EV-Tied Microgrids: Economic Dispatch, Power Quality, and Environmental Impact"

Economic dispatch remains the primary focus in research on EV-integrated microgrids, as it plays a crucial role in reducing operational losses for utilities and minimizing the cost of purchasing energy from the grid, especially when electricity prices are high for consumers. A breakdown of the research focus reveals that economic dispatch is the most extensively studied area, accounting for 43% of the reviewed literature as depicted on Fig 10. This emphasis stems from its direct impact on optimizing energy use and cost-efficiency within microgrids.

In contrast, a combination of economic dispatch and power quality optimization has garnered 27% of the research attention, reflecting the growing interest in maintaining grid stability while also optimizing costs. Meanwhile, 13% of the studies focus specifically on power quality issues in EV-integrated electrical networks, addressing concerns related to voltage regulation, frequency stability, and other performance parameters. Only 3% of the research examines all three areas—economic dispatch, power quality, and environmental impact—due to the inherent complexity of addressing multiple, often conflicting objectives, which increases the computational demand. Finally, the remaining 3% focuses solely on the environmental impact, prioritizing sustainability over other operational concerns.

This distribution highlights the ongoing challenge of balancing multiple optimization objectives, where trade-offs between cost, quality, and environmental considerations create a complex problem requiring significant computational resources to solve effectively."

8. Conclusions

This paper provides a comprehensive overview of microgrid energy management, focusing on optimization techniques classified as classical, heuristic, and hybrid approaches. It examines the challenges posed by the high penetration of renewable energy sources and the integration of electric vehicles (EVs), highlighting their economic, environmental, and technical impacts. The review finds that 44% of recent studies focus on economic dispatch, with heuristic methods, particularly particle swarm optimization (PSO), being the most prevalent due to their simplicity and efficiency. Although heuristic methods offer quick solutions, they only approximate optimality, making hybrid approaches more effective by combining accuracy and scalability. The paper concludes that EVs are becoming central to enhancing microgrid stability, reducing greenhouse gas emissions, and addressing the stochastic nature of renewables. Future directions suggest the use of advanced predictive methods such as adaptive model predictive control (AMPC) and machine learning to manage complex, multi-objective problems more effectively.

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