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Recent trend and future prospect in optimization of electric vehicle charging: a systematic review

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ABSTRACT

Electric vehicles charging (EVs) must be done optimally to minimize the impact it causes. EVs are being recognized as a potential way to decrease greenhouse gas emissions and combat climate change. However, there are still difficulties in optimizing these systems to minimize operating costs and EVs charging waiting times. This study investigates several industrial, commercial and residential charging stations. The primary objective of this study is to systematically review the existing literature on optimizing EV charging. The collection of data was centered on scholarly articles released between the years 2018 and 2023 from Scopus, IEEE Xplore. This study presents a systematic literature review of optimizing EVs charging. As a result, 43 EVs charging optimization studies were obtained which were investigated and studied further. Identify and analysis the selected studies, there are two research topics and trends most frequently addressed by researchers: scheduling and coordination. The four most applied methods in EVs charging are identified: particle swarm optimization (PSO), genetic algorithm (GA), linear programming (LP) method, and evolutionary algorithms (EA). Future research directions: develop advanced optimization algorithms, investigating the integration of renewable energy sources into the charging infrastructure, exploring the potential of vehicle-to-grid (V2G) services, studying the impact of EVs charging on the power grid and developing strategies, considering the optimization of charging schedules and coordination strategies for large-scale EVs fleets.

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1. INTRODUCTION

The world community is currently worried about climate change. This situation forces the government to take a policy to shift the use of the main transportation energy from petroleum to renewable energy to reduce CO_2 emissions [1], [2]. The private sector has shifted transportation technology from internal combustion engines (ICE) to electric vehicle (EV) starting a decade ago [3]. In recent years, almost all over the world there has been a rise in the purchase of EVs and plug-in electric vehicles (PEV).

The highly notable rise in the quantity of the proliferation of EVs for both residential and commercial use, coupled with the swift expansion of EV charging infrastructure, engenders heightened risks. This escalation in the quantity of PEVs necessitates attention will trigger an extreme surge in demand for shared charging during peak hours. This increase can have positive and negative impacts on power distribution network operations due to overloading of transformers, cables and feeders [4], [5]. Apart from that, EVs have the potential to be a solution in the peak shaving and valley filling grid business in peak load conditions by transferring energy from the EV battery to the grid under the vehicle-to-grid (V2G) service concept [6], [7]. On the other hand, random and uncoordinated EV charging systems can cause serious impacts to the distribution network such as increasing peak loads, which in turn causes high power losses, voltage violations, voltage imbalance, reduced transformer life, and harmonic distortion [8]-[10].

The operation and charging of EVs necessitates the implementation of optimal strategies, as elucidated in reference [11]. The objective behind such optimization is to minimize the costs associated with charging and battery degradation [12]. Additionally, the optimization process aims to reduce the time and temperature required for charging, thereby enhancing the overall efficiency of the EV system [13]. Furthermore, the optimization techniques can be utilized for the purpose of scheduling PEVs parking lots [14], which can have a significant impact on the overall grid stress alleviation [15]. Therefore, it is crucial to explore and implement optimal approaches for the operation and charging of EVs, taking into consideration various factors such as cost, time, temperature, parking lot scheduling, and grid stress.

The subsequent segments of this document are methodically arranged as follows: the second segment introduces the method employed to execute the systematic review. The third segment delineates the findings of the review and subsequent discourse. The fourth segment brings the document to a close and emphasizes forthcoming undertakings.

The primary objective of this study is to systematically review the existing literature on optimizing EV charging. This research additionally offers an examination of recent investigations concerning EV charging. Therefore, this review is critical for identifying research gaps, and providing recommendations for future research and development efforts.

Optimization is a methodical process for finding peak candidate solutions that can be calculated by maximizing or minimizing the value of an objective of a space exploration by selecting a certain number of variables [16]. Meanwhile, a multitude of academicians possess diverging perspectives concerning intelligent soft computing techniques in the context of exploring novel resolutions that can be attained via conventional methodologies in the realm of infrastructure charging optimization. Moreover, recent investigations have delved into the utilization of linear optimization or non-linear methodologies by scholars to accomplish their respective target functions. In truth, a majority of the scrutinized cases unveiled that researchers were capable of implementing either single objective or multi-objective optimization. In accordance with this research paradigm, stations designated for the recharging of batteries in EVs and EV require charging infrastructure to charge the batteries.

2. METHOD

This section establishes the systematic and methodical process of studying written materials that is used to ensure the thoroughness and reproducibility of this investigation. To ensure the quality of the systematic review, the literature search was conducted using a foundation of scholarly resources the preferred reporting items for systematic reviews and meta-analyses statement (PRISMA) [17] as shown in Figure 1. The stages used are as follows:

a. The first stage of the systematic review is to formulate research questions based on gap analysis. The following research questions were defined to achieve the research objectives: i) what are the most discussed topics in EV charging optimization?; ii) what methods are used to optimize EV charging?; and iii) what are the future research directions for EV charging optimization?
b. Stage 2 identifies relevant electronic search databases; We systematically searched two electronic databases (IEEE Xplore and ScienceDirect). We used the inclusion criteria to help us choose the articles: The keywords used for the search were: i) "optimization of EV charging", ii) "optimal charging of EV", and iii) "EV charging optimization".
c. Stage 3, search results are filtered and chosen based on the following inclusion selection criteria:
   Criteria i: The paper category includes Journal articles and Conference Proceedings
   Criteria ii: The publication year: 2018-2023
   Criteria iii: Field of research: EV charging
   Criteria iv: Content: studies that discuss EV charging optimization and optimization methods. Included experimental, numerical, and simulation studies. Studies addressing purely EV charging are not included. Every review paper was excluded.

Criteria i and ii are applied automatically using features were considered, and duplicate entries were eliminated in the electronic database search. The results were manually evaluated against criteria iii and iv of the selection criteria were considered, and duplicate entries were eliminated. From the search results, 160 articles were found. Next, the author downloads the chosen articles, investigates and analyzes each article.

To collect articles, the authors use articles on search sites. In the initial step, the author imports article references using the RIS text format. In this situation, the author made the RIS text since it is easier to do in Mendeley Desktop Software. After uploading references, the system reads several articles. The second step is screening the title and abstract. At this stage, the author reviews the title and abstract and decides whether to fail or include a basic article regarding the relationship to the research objectives. The following step is a thorough text review. In the final step, extraction is carried out. From the 160 original articles from the search results, 43 articles were obtained at the extraction stage regarding studies on optimizing EV charging and the methods used. During the review, chosen articles were examined using the captured keywords: i) topic, ii) reference, and iii) quantity.

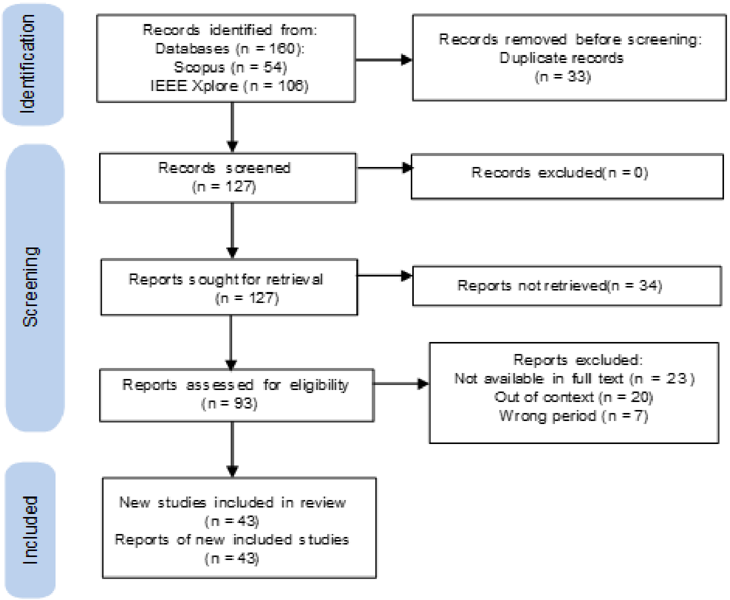

Figure 1. Stages of the systematic review

3. RESULTS AND DISCUSSION

The literature search yielded 43 peer-reviewed articles meet the inclusion criteria. The findings given in this study work are divided into three major categories: i) most discussed topics in EV charging optimization, ii) methods used in EV charging optimization, and iii) future research directions for EV charging optimization.

3.1. Research topic in electric vehicle charging optimization field

An investigation into the research topic of optimizing EV charging has been carried out. There are two research topics most frequently addressed by researchers, namely scheduling (23%), coordination (14%). Next, charging station deployment or allocation (7%), estimation (5%), energy management (5%), EV charging station site selection and capacity allocation (5%), renewable energy-based EVs charging station (5%), battery efficiency or management (5%), and configurations (5%). In addition there are ten individual topics each (2%) as shown in Table 1.

The first trending topic is scheduling where the EV charging strategy is based on blockchain [18], decentralized algorithm [19], adaptive dynamic programming [20], and multi-energy micro-grid model [21]. The optimal EV charging strategy uses particle swarm optimization (PSO) [22] and genetic algorithm (GA) [23]. Optimization of EV charging scheduling in urban village networks considering energy arbitrage and distribution cost, two-layer optimization method [24], backtracking method [25], discrete event approach [26], two adaptive charging algorithms [27], respectively is reduces charging costs for EVs' owners, reduces the loss of arbitrage benefits, reduces peak load by 14%, reduces total elapsed time, effectively tested on real case studies, and can improve congestion and waiting time.

The second topic is coordination. Ayyadi *et al*. [28], coordinated EV charging optimization using linear programming (LP) can reduce EV charging costs by 50%. Bitencourt [29] uses Monte Carlo simulation so that coordinated charging reduces load peaks and fills valleys. Chen *et al*. [30], applies a two-stage optimization model so that the total cost of charging pile is reduced and improves the precision of the level of charging facility planning.

Table 1. Research topics in literature

Topics	References	Quantity
Scheduling	[18]-[27]	10
Coordination	[28]-[33]	6
Charging station deployment/allocation	[34]-[36]	3
Estimation	[37], [38]	2
EVCS site selection and capacity allocation	[39], [40]	2
Renewable energy-based EVs charging station	[41], [42]	2
Multi-objective EV charging	[43], [44]	2
Battery efficiency/management	[45], [46]	2
Energy management	[47], [48]	2
Optimization of EV charging configurations	[49], [50]	2
Reducing emission	[51]	1
Neurodynamic algorithms in microgrids and sparse signal reconstruction.	[52]	1
Tuning parameters of solving constraint integer programs (SCIP) for scalability	[53]	1
Distributed control strategy	[54]	1
Including line current limitations and power quality effects	[55]	1
Bi-level robust optimization of EV charging stations	[56]	1
Effective use of parking spaces near commercial buildings	[57]	1
Energy losses during EV charging	[58]	1
Participation of aggregated EVs in energy and frequency reserve markets	[59]	1
Competitive pricing	[60]	1

3.2. Current state-of-the-art electric vehicle charging optimization method and approaches

Since 2018, thirty-four approaches were tested and offered as the best method to optimize EV charging. Summary of state-of-the-art methods used in EV charging optimization is shown in Figure 2. From the thirty four methods shown in Figure 2, there are four methods that are most widely applied in optimizing EV charging. They are: i) PSO, ii) GA, iii) LP method, and iv) evolutionary algorithms (EA). PSO, GA, LP, and EA are the four most widely applied methods. This method was used in 39.9% of the selected studies where the others were individually 2.9% as shown in Figure 3.

There have been many studies discussing the optimization of EV charging but there is no agreement on the method that has the best comparative performance of optimization techniques. Di *et al*. [18] reported that an EV charging scheduling strategy based on PSO can reduce the charging costs of most EVs significantly. Lu *et al.* [22] an improved version of the intelligent algorithm is proposed to minimize charging costs, and the method is validated through four case studies, demonstrating advantages such as reduced charging costs and faster charging for EV owners.

Research conducted by Mohamed *et al.* [45] presents an optimal model for charging EV using the PSO algorithm, allowing scheduling of EV charging based on user needs and arrival or departure times, with four different strategies applied. The PSO algorithm in [39] can easily get stuck in local best solutions, while fuzzy neural network has advantages but struggles with lack of data. The hybrid algorithm GA-PSO performs the best in convergence and efficiency, but further research is needed for improvement.

In addition [34], an optimization model using a GA was developed to determine the number and location of EV charging stations, which aims to minimize costs and improve service quality by reducing travel distances between demand points and stations. Altundogan *et al*. [40], a GA approach based on graph theory is used to determine the optimal locations for charging stations in urban areas, by considering the path relation and distance information between reference nodes in a weighted graph, resulting in a suitable method for distance-based charging station location determination. Srithapon *et al*. [23] presents an optimized strategy for EV charging scheduling in an urban village, considering energy arbitrage and distribution network costs, using a GA, resulting in reduced energy arbitrage loss, peak demand, power loss, and transformer aging.

Niccolai *et al*. [35], a new optimization environment has been introduced to apply EA to the problem of deploying EV charging stations, providing flexibility and avoiding general assumptions, while addressing scalability and non-linearity, managing infeasible solutions, and combining multiple performance indicators. The study compares the proposed approach with a greedy optimization. The optimization environment includes design variables, unfeasible solutions management, and cost function.

Borray *et al*. [42] reported a method for optimizing EV charging rates to maximize power delivery, while managing voltage constraints and load on the grid. The proposed LP has been tested and proven to be effective for implementing charging strategies and for energy planning studies. Ayyadi *et al*. [28] LP in this study reduces EV charging costs by 50% and 38% for 100% and 50% EV penetration rates, compared to previous methods, as demonstrated in a residential low voltage distribution network, respectively.

Based on the articles reviewed, future research directions for EV charging optimization:

a. Further research can focus on developing advanced optimization algorithms that can handle the increasing complexity of EV charging systems.
b. Investigating the integration of renewable energy sources into the charging infrastructure to promote sustainable and clean charging solutions.
c. Exploring the potential of V2G services, where EVs can transfer energy back to the grid during peak load conditions, to alleviate stress on the power distribution network.
d. Studying the influence of EV charging on the power grid and developing strategies to mitigate issues such as overloading of transformers, cables, and feeders.
e. Considering the optimization of charging schedules and coordination strategies for large-scale EV fleets, taking into account factors such as user preferences, charging station availability, and grid constraints.

There have been many articles discussing charging EVs. Charging of EVs should be done optimally by considering several constraints. This systematic review aims to review articles on EV charging optimization, the identification of the topics discussed by researchers and the identification of gaps in research are crucial endeavors. The literature review articles in this research are small in number, but in reality, this paper contributes to optimal EV charging.

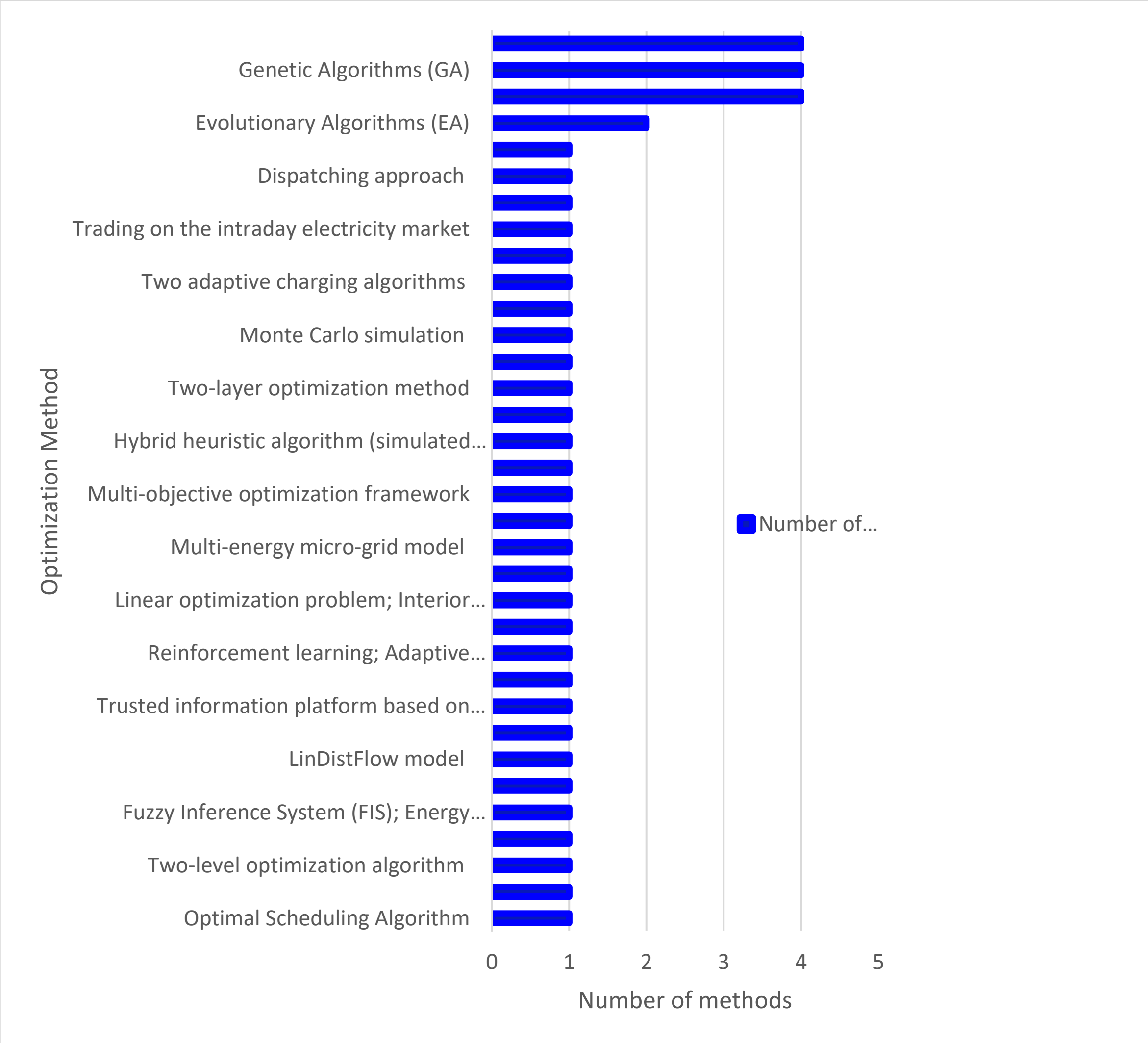

Figure 2. Methods used in optimization of EV charging

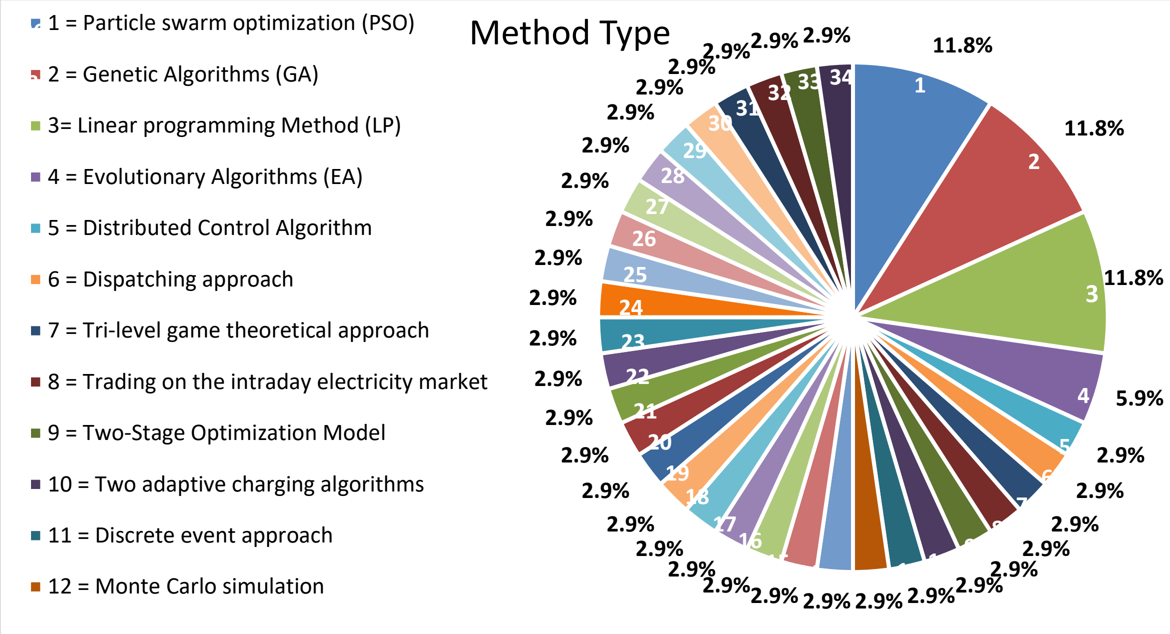

Figure 3. Distribution of studies by method type

4. CONCLUSION

This systematic review has provided examination of the current state of knowledge regarding EV charging. The collection of data was centered on scholarly articles released between the years 2018 and 2023, sourced from Scopus, IEEE Xplore. This paper provides a systematic literature review of optimizing EVs charging. As a result, 43 EVs charging optimization studies were obtained which were investigated and studied. Identify and analysis the selected studies, there are two research topics and trends most frequently addressed by researchers: scheduling and coordination. Thirty four different methods have been applied to optimize EVs charging. From the thirty four methods, the four most applied methods in EVs charging are identified. They are PSO, GA, LP method, and EA. Future research directions: develop advanced optimization algorithms, investigating the integration of renewable energy sources into the charging infrastructure, exploring the potential of V2G services, studying the impact of EVs charging on the power grid and developing strategies, considering the optimization of charging schedules and coordination strategies for large-scale EVs fleets.

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